Hydroclimate trend analysis of Upper Awash basin, Ethiopia

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Abstract

Ethiopia considered to have abundant water resources potential is facing flood and drought possibly from poor water resource management and reluctant policy. Awash river basin classified in to upper, middle, and lower crosses Ethiopian plateau through the Afar desert. Among the basin classes, the upper basin is socio-economically important wherein the early and modern agriculture start is the most irrigated basin. Addis Ababa the capital and different major towns are getting their domestic Water supply from this basin. The study aimed to assess the basin's hydroclimate variability under the climate change during study time series. Basin's Metrological trend is analyzed with systematic topographical classes as Lowland, midland, and highland. Lowland (Mojo and Bishoftu station) revealed nonsignificant increasing trend except for the Bona and Birraa season respectively. Midland area stations revealed a seasonal decrease with precipitation except Asgori station is increasing in the Birraa season. Highland area stations exhibited a decreasing trend annually and in Arfaasaa seasons except Sendafa station got an increasing trend. Addis Alem station decreased Annually at a 95% significance level while other are statistically insignificant. The streamflow of the basin evaluated with Awash-Hombole and Mojo main tributary river flow. Awash-Hombole main tributaries resulted in increasing trend annually and during Ganna season. Berga, Holota, Melka-Kunture and Hombole stations are insignificantly increasing annually. Mojo main tributary resulted in a significant decreasing trend during the Arfaasaa, Ganna and Birraa season at 99% significant level. Basin streamflow change within the study time series is observed within the model's observation confidence interval of 95% except for the 1996 steam flow. Therefore, there is change observed within the basing both with rainfall and streamflow according to basin's topographic nature. Thus, the basin's hydroclimate variated by 11.38% and 38.19% rainfall and streamflow respectively from the mean value within the study time series.

Introduction

Ethiopia is considered to have abundant water resources potential (Chemeda et al., 2006) and further, some expressed the country is the East African water town. Contrarily, it is facing flood and drought from poor water resource management with reluctant policy (Dereje et al., 2015; Hailu et al., 2019). Hence basic water resource development with Optimal utilization is important for sustainable agriculture-related economic development (Dereje et al., 2015). The country has 12 main transboundary flowing rivers except for the Awash river basin and the Rift lakes (Alemayehu et al., 2015; Azega et al., 2018; Tenalem et al., 2008). Those basins water resources are under hydro-climatic variability threat from high spatial and temporal change effects. Thus, such variability may lead to major socio-economic challenges which has necessitated the need to investigate the relationships between climate and water resources (Field et al., 2014; Tadese et al., 2019).

Historically, the first hydroelectric dam built in the upper Awash basin named Aba Samuel dam in 1932 and later the Koka dam in 1960. It is river basins wherein modern agriculture was introduced as the early 1950s. This basin has both early farming practices and limited mechanized farming practices. Therefore, it is most irrigated so that it is the economically most important basin of the country (McComick & Peden, 2004). Furthermore, this basin is a water-stressed basin from intensive irrigation and domestic water supply mainly along with its tributes during April to June (Awash Basin Authority, 2017) for that the river basin's discharge is decreasing since 1981 (Gedefaw et al., 2018). Ministry of the water resource and Energy introduced the Awash Valley Authority (AVA), 1962 to solve persistent problems of water stress, infrastructures plan and develop the basin water resources administration (Awash Basin Authority, 2017; Reta et al., 2018). But AVA failed to provide its full mandate from institutional turnover which alters the country's socio-political situation (Awash Basin Authority, 2017). Upper Awash the water-stressed basin from urban expansion and irrigation development may easily be affected by existing climate change. Therefore, hydroclimate change assessment and quantification of its change are important in water resource planning and management. Accordingly, this study aimed to assess the hydroclimate change of the study time series under the existing climate change.

Methods

Description of Upper Awash basin

Scholars deal with the Awash basin in three basin parts upper, middle, and lower Awash basins from its climatological, physical, socio-economic, agricultural, and water resources characteristics(Awash Basin Authority, 2017; Edossa et al., 2010; Meron Teferi et al., 2018). Upper Awash is a river basin that crosses the Ethiopian plateau to the main rift and it covers 11402 km^2. Upper Awash river flows from above 3000m to 1600m above mean sea level (a.m.s.l) at headwaters Ginchi a location found about 75km south Addis Ababa and Koka Dam within its basin respectively. The basin is delaminated with the Abay River basin form the western side, the Omo-Gibe, and Rift Valley Lakes basin to the south-west and the Wabi Shebele River basin from the south-east (Henok et al., 2014). Specifically, the basin extends from 38.52 to 53.23 Longitude and 8.79 to 10.26 latitude according to figure 1.

Upper Awash basin is part of the Ethiopian climate that mainly controlled by the seasonal migration of Intertropical Convergence Zone (ITCZ) and associated atmospheric circulations related to the complex topography of the country (Gudmundsson, 2001). The country has a diversified climate from the semi-arid desert type in the lowlands to humid and warm (temperate) type in the southwest. Accordingly, the Awash basin crosses the humid from its upper basin to arid at the lower basin. This basin got 27.18^0C mean annual temperature, and mean 25.87 and 28.98^0C minimum and maximum temperature respectively (Gedefaw et al., 2018).

Addis Ababa the capital, Bishoftu city and other major towns are located in the upper Awash basin. The rural area of the basin is dominated by farmland and cereal crops that believed to feed these cities and towns are from this basin. Based on the land use dynamism from urban expansion within the upper basin, the observed the most progressive climate change resulted in water stress (Meron Teferi et al., 2018) and agricultural economic tension.

Figure 1 Upper Awash basin location map

Method

Climate change and water resource fluctuation are inseparable natural events. Whether it is a quantifiable or unquantifiable change in these events might result in hydroclimate change and it could devastate socio-economy. To assess and evaluate the existing long-term climate change effect in Upper Awash basin water resource fluctuation, climate and streamflow data are subjected to topographic traced hydroclimate statistical trend analysis. To evaluate the hydroclimate trend of the basin, Mann Kendall and modified Mann Kendall's trend analysis with Sen's slope estimator is used. The Mann Kendall and modified Mann Kendall's trend evaluation is based on the data autocorrelation.

Data

The upper Awash basin hydroclimate trend analysis for the 1991 - 2015 time series or basin's 25 years periodical hydroclimate elements precipitation, temperature, and streamflow are subjected to statistical trend evaluation. The climate data of more than 15 stations within the basin are collected from Ethiopian

National Meteorological Agency (NMA) and based on data consistency eleven stations (Table 1) are subjected to trend analyses.

Table 1 Precipitation stations and their missing Values

Likewise, daily data of seven streamflow gauging stations (Table 2) within the basin collected from the Ministry of Water and Energy. These daily data are converted to monthly based to evaluate its seasonal flow fluctuation. So, upper Awash basin river flow fluctuation is evaluated from the study time-series change in streamflow. Hence the climate change is possibly manifested in the change of precipitation that believed to be observed in streamflow regime change according to section 2.2.5.

Table 2 streamflow gauging stations

Filling missed data

The problem of missing value could be from machine failure and/or from the negligence of station readers. Data inconsistency observed is common problems in developing countries. Thus station selection was based on reasonable amount of missed data, considered to solve with numerical filing method. This study used a filling method based on the amount of missing data within the basin during the study time series. Different scholars used various methods to fill missed data in the statistical hydrometeorological analysis. For this basin hydroclimate trend evaluation, stations with the missing value of more than 15% are excluded to reduce the computational errors. Hence stations with missing gaps $< 15\%$ and $> 10\%$ were filled with the application of numerical normal ratio method and stations having missing value <10% are filled with simple linear regression with stations that nearby rainfall station (McCuen, 1989, pp. 76–77) according to equation (1) and (2) respectively.

$$Rs = \frac{Rs}{n} + \sum_{i=1}^{n} \left(\frac{\mathrm{Ri}}{Ri} \right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

where s and i are annual average rainfall at a station with missing value and neighboring gauges respectively, Ri is the rainfall in the neighboring gauge and n is the number of neighboring stations.

$$\mathrm{Px} = \frac{1}{n} + \sum_{i=1}^{n} \frac{\mathrm{Pi}}{n} \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Where Px is a missing value, Pi is the record from the neighbor and n is the number of the neighboring stations.

Homogeneity test

The homogeneity test is another process used to see the consistency of recording stations' data. When station location changes and/or technical problems happened data record discontinuity could happen. Thus, homogeneity management is the most crucial part of hydroclimate trend evaluation and it is useful to see data deviation from the mean. The homogeneity is tested with Pettitt's test, Standard Normal Homogeneity Test (SNHT), Buishand's method and Von Neumann's test, and hence the cumulative deviation is used to detect the inhomogeneity (Daniel et al., 2017), the possibility of homogeneity test from the partial sum or cumulative deviation from mean is noted by Bushand (1982) according to the following equation (3).

$$\mathrm{Sk}^{*} = \sum_{i=1}^{k} (yi - y) \qquad k = 1, 2, \dots\dots n, \quad \dots\dots\dots\dots\dots\dots\dots (3)$$

The term Sk * is the partial sum of the given series. If there is no significant change in the mean, the difference between yi and ȳ will fluctuate around zero (y is the annual series and y is the mean). The significance of the change in the mean is calculated with 'rescaled adjusted range' R, which is the difference between the maximum and the minimum of the Sk* values scaled by the sample standard deviation is:

$$R \;= \frac{\max \mathrm{Sk}^* \;\; - \min \mathrm{Sk}^*}{\mathrm{SD}} \quad 0 \leq k \leq n \;\ldots\ldots.. \;\ldots\ldots\ldots\ldots\ldots..(4)$$

The time series trend analysis can be influenced by the existence of autocorrelation that happened from the occurrence of repeated data values within trend data analysis. Furthermore, the auto-correlation test is determining the randomness of the hydroclimatic time data series and influences the significance level of its trend. So, the lag-1 autocorrelation is calculated as the modified Mann Kendall trend analysis is used when the autocorrelation exists. The existence of autocorrelation is used as a base for different scholars to reduce the possible exaggeration in the significance of trend analysis or it may lead to underestimating the trend. For example, Bayazit & Önöz (2007) and Hamed (2009) discussed the Error I (error of accepting the null hypothesis) and error II (error of rejecting the null hypothesis). Therefore, the Pre-whitening method is the most common method to solve problems related to autocorrelation. Pre-whitening importantly reduces the false detection of a trend when it does not exist (Bayazit & Önöz, 2007).

Mann Kendall Statistics model

The widely utilized non-parametric Mann Kendall/ modified Mann Kendall (Yue & Wang, 2004) statistical trend and Sen's Slope (Sen, 1968) analysis is considered to quantify hydroclimate trend of the basin. For the Mann–Kendall test is a nonparametric test in which the rank of data values within a time series are compared.

Mann Kendall's statistics test (equation 5) assumes that observations are independent and random. There is no serial correlation in observations. The test statistic S and critical test statistics Z are described as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \; (Xj - Xi) \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The trend test is applied to Xi data values (i = 1, 2, . . ., n) and X (j = i + 1, 2, . . ., n). The data values Xi are used as reference points to compare with the data values of Xij , which are given as (6):

$$sgn(S) = \begin{cases} 1, & if\ (Xj - Xi) > 0 \\ 0, & if\ (Xj - Xi) = 0 \\ -1, & if\ (Xj - Xi) < 0 \end{cases} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where X_i and X_j are the values in periods i and j. When the number of data series is greater than or equal to 10 (n $_{-}$ 10), the MK test is then characterized by a normal distribution with the mean E(S) = 0 and the variance Var(S) is equated as (7):

$$\mathrm{Var}\,(S) = \frac{n\,(n-1) * (2n+5) - \sum_{k=1}^{m} \;\; tk * (tk-1) * (2tk+5)}{18} \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where m is the number of the tied groups in the time series, and tk is the number of data points in the k th tied group.

The critical test statistic or significance test Z is as follows (8):

$$Z = \begin{cases} & , \;\; \& if\ \ S > 0 \\ 0, \;\; if\ S = 0 & \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8) \\ & , \;\; \text{if S} < 0 \end{cases}$$

when Z is greater than zero, it indicates an increasing trend. When Z is less than zero, it represents a decreasing trend and its significance level at critical values of Z-score where it is greater than $+ 1.65$, $+ 1.96$, and $+ 2.58$ at 0.1, 0.05 and 0.01, respectively.

Original Mann Kendall test neglects the effects of serial correlation. Lately, Yue and Wang, (2004) considered the autocorrelation effect and develop the Modified Mann Kendall test.

Sen's Slope

Quantifying existed increasing or decreasing trend can be done with non-parametric Sen slope. Furthermore, the Sen slope estimator is used to evaluate the amount of time series trend change (Salmi et al., 2002) when the trend is assumed to be linear according to equation 9 (Daniel et al., 2017).

$$D\left(t\right) = Q\left(t\right) + B \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where D(t) is increasing or decreasing trend function of time. S is slope and B is intercept (constant).

Thus, the slope of each data pair Q_i is expressed according to equation (10):

$$Qi = \frac{Xi - Xj}{j - i} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where $j > i$. i.e. Xj is data reading time series j while Xi is data reading time series at time series.

Topographic based hydroclimate change evaluation

Change of rainfall and temperature evaluation can be evaluated with elevation. So, the basin has an elevation range from about 3400m to 1577m a.m.s.l. This variated topography is systematically classified into three see figure2. The first class was termed lowland which ranges from 1577 to 1990 m a.m.s.l, that has about 361.16mm mean rainfall, the midland class is the elevation from 1990 to 2250 m a.m.s.l which has 354mm mean rainfall and the highland area is the catchment that elevated from 2250 to 3400m a.m.s.l. with 137.35mm mean rainfall. DEM of the study area is used for topographic classification according to (Figure 2) using ArcGIS 10.3.

The upper Awash basin is the basin from Awash river headwater to Lake a koka. Thus, the river gets two river inlets at the Koka lake. When evaluating these upstream rivers, it is systematically approached by evaluating river tributaries of Awash Hombole and Mojo. Because both rivers from upper Awash Hombole and Mojo river crosses the earlier explained elevation difference.

Linear regression

The relationship between rainfall and streamflow evaluation will be evaluated with linear regression. The regression model is developed from mean streamflow and rainfall in the basin. It is calculated using equation (11).

$$D = Si \ + \ RiRb \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where D is basin mean streamflow, Si stream flow intercept, Rb basin mean rainfall and Ri rainfall intercept. Change in the streamflow will be controlled by the basin rainfall condition.

Figure 2 Elevation based classified map of upper Awash Basin

Result and Discussion

The climate of the Awash basin is traditionally known by four seasons. These seasons are *Arfaasaa* refers to Spring (March, April, and May), *Ganna* is Summer (June, July, and August), likewise,*Birraa* is Autumn

(September, October, and November) and*Bona* is Winter (December, January, and February). The basin is known by wet season during *Arfaasaa* and *Ganna* including September from *Birraa* season while the rest seasons are dry. That means months from April to September are the wet and hot times. So, the basin showed an increasing trend in different stations with various seasons and a decreasing trend as well. Here the trend is expressed as increasing and decreasing while the statistical significance level is used to show the level of confidence to quantify basin's hydroclimate trend.

The upper awash river basin has two great streams that enter the Koka reservoir. These streams are the Hombole and Mojo main tributaries. These tributaries are exhibiting seasonally incremental and decremental trend.

For the entire hydroclimate trend analysis daily data elements are collected to evaluate seasonal fluctuation of study time series. Because the socio-economy of the basin is influenced seasonally.

Seasonal and annual Meteorological analysis

Precipitation of eleven selected stations within the basin is evaluated for 1991 to 2015 time series (Figure 3). All stations' daily data were converted to monthly for evaluation since seasonal trend change is considered as important. The basin during 25 years of study time series had got 1019.41mm mean rainfall. Furthermore, it had 1339.78 mm maximum and 872.76mm minimum rainfall during 1993 and 1997 respectively. The wet seasons *Arfaasaa* and *Ganna* the most basin's economically important seasons with annulling trend results are considered.

Lowland stations (Bishoftu, Mojo, and Hombole) show a change in precipitation and temperature. These stations have annually and seasonally increasing trend with precipitation and temperature. The Hombole station seasonal temperature is autocorrelated except during the *Arfaasaa* season. So, the analysis is subjected to a modified Mann Kendall trend analysis that resulted in an increasing trend. This annual increasing trend is statistically significant with a 95% significance interval. Precipitation of Hombole station resulted in an insignificant increasing trend. Mojo station revealed insignificantly increasing trend except for the *Birraa* season. During the *Birraa* season, precipitation and temperature of the station significantly increasing with 95% and 90% significance level respectively. Bishoftu station insignificantly increased the precipitation annually and during all except Bona seasons. Likewise, its temperature got increased annually and seasonally.

Figure 3 Upper Awash basin mean rainfall since 1991 to 2015

Midland area stations (Sebata, Kimoye, and Ginchi, Asgori) revealed seasonal decrease with precipitation except Asgori is increasing in the *Birraa* season. So, it is possible to say all stations resulted in a decreasing trend of seasonal precipitation in 25 years of study time series. These stations increased with maximum temperature at Kimoye and Asgori stations while decreasing trend resulted from Sebata and Ginchi stations. The annual and seasonal precipitation trend of Sebata station is significantly increasing. Moreover, except *Bona* season of Kimoye and*Ganna* season of Asgori, annual and seasonal trends of temperature significantly increase at 0.1 critical value. But Ginchi and Sebata stations are insignificantly decreased trend with maximum temperature.

Precipitation of Highland area stations (Addis Ababa, Sendafa, Ejere, and Addis Alem) exhibited a decreasing trend annually and in*Arfaasaa* seasons except Sendafa station got an increasing trend. Addis Alem decreased Annually at a 95% significance level while other stations are statistically insignificant. During *Ganna* season, Addis Alem and Addis Ababa stations increased insignificantly while Sendafa station significantly increased. Contrarily, Ejere stations significantly decreased at 0.05 critical value. Highland stations exhibited an annually decreasing trend except for Sendafa station.

Table 3 Trend analysis result of Precipitation

Hence highland stations are lacking temperature data, Addis Ababa station is considered for the trend analysis. Thus, the station has resulted in an increasing trend annually and during seasons. Statistically annual trend of maximum temperature and during*Ganna* and *Birraa* seasons of minimum temperature significantly increased. The detailed analysis is expressed in (table 3).

Seasonal and annual streamflow evaluation

Upper Awash river crosses the part of the Ethiopian plateau via Bacho plain to the Koka dam that lays in the main Ethiopian rift floor. Most of the main tributaries are heading from a major urban area of the basin to the Awash River. Technically, it is possible to classify these tributaries into Awash-Hombole and Mojo's main tributaries. Because the Koka dam inlet is mojo and awash-Hombole river downstream.

Awash-Hombole is the main tributary from Awash-Melka kunture that comes from Awash head flow with different tributaries and it joins with Akaki's main tributary at Geba Robi (472731.62m E, 953030.32m N) type locality. This river crosses the three topographic classes (figure2) used for the Metrologic trend. Dominantly it flows from highland and midland topographic class.

Homogeneity test and autocorrelation detection are carried out before the streamflow trend operation. Correlated annual data is detected at Akaki and Mojo station. While Awash Bello, Berga, and Hombole stations are correlated during the Bona season.

Berga and Akaki stations are significantly correlated during the*Arfaasaa* season and Mojo station is correlated in *Ganna*season. Significantly autocorrelated data trend analysis was operated with modified Mann Kendall trend and uncorrelated data is operated with original Mann Kendall trend test according to table 4.

Awash-Hombole upstream tributaries exhibit both a statistically increasing and/or decreasing trend. Berga river significantly increasing annually and during *Arfaasaa* and *Bona* seasons at 95% significant level. During the *Ganna* season, it is significantly increasing at a 90% significance level while during the *Birraa*season it increases that doesn't exhibit any statistical significance. Contrarily, Akaki tributary heading from the Entoto scarp which differentiates the Abay and Awash basin (Tenalem et al., 2008) resulted in a statistically decreasing trend annually and during all seasons.

Awash Balo station resulted significantly decreasing trend during the*Arfaasaa* season at a 5% critical value while Melka kunture, Berga, Hombole and Holota stations resulted in a statistically insignificantly increasing trend.

Table 4 Trend analysis result of Streamflow

Ganna season is known as the heavy season in the entire basin. But stations like Akaki, Hombole, and Holota have resulted in a decreasing trend while Berga, Melka kunture and Awash Balo are shown an increasing trend. During the *Birraa* season, Akaki station decreased significantly at 1% critical value while Holota station resulted in a statistically insignificant decreasing trend. But Awash Belo, Berga, Melka kunture and Hombole stations are increasing with statistically not significant. In*Bona* which is the driest season of the sub-basin also exhibits both increasing and decreasing trend. Akaki, Awash Belo, Melka kunture and Berga resulted in a decreasing trend. But the first two stations significantly decreased at a 5% critical value. Contrarily, Holota and Hombole stations show insignificantly increasing trend. The basin resulted in an annually increasing trend within Melka Kunture, Berga and Awash Belo. The decreasing trend is observed with Akaki, Holota and Hombole stations. Though the basin decreased or increased with annal trend analysis, both are statistically not significant. Generally, from Awash-Hombole main tributaries, Awash-balo, Berga, and Melka-Kunture resulted in increasing trend annually and during *Ganna* season. Berga, Holota, Melka-Kunture and Hombole stations are increasing annually with statistically not significant.

Mojo station resulted in a significantly decreasing trend during the*Arfaasaa* season at 1% critical value. During *Ganna* season Mojo station resulted in a decreasing trend. During the *Birraa*season, Mojo stations decreased significantly at 1% critical value. During *Bona* which is the driest season of the sub-basin as expressed earlier Mojo stations show insignificantly increasing trend. But the station resulted in a decreasing trend annually.

Rainfall and Streamflow relationship

The rainfall influences streamflow of River basin. From the linear regression method, the upper Awash basin rainfall and streamflow are evaluation the relation is developed (fig 4).

The change in rainfall resulted in a change of streamflow (Figure 4). Basin streamflow change within the study time series is observed within the model's observation confidence interval of 95% except for the 1996 steam flow. Generally, there is change observed within the basin both with rainfall and streamflow. Thus, the basin's hydroclimate variated by 11.38% and 38.19% rainfall and streamflow respectively from the mean value within the study time series. The hydrologic variation could be from the existing climate change.

Figure 4 Regression of basin streamflow(m3/s) by its Rainfall(mm)

Conclusion

The upper Awash basin hydroclimate trend evaluation is carried for 25 years which is from 1991 to 2015 time series. This analysis is done with the basin's hydroclimate elements precipitation, temperature, and streamflow. In the basin's precipitation and climate trend analysis topographically, the basin is classified into highland, midland, and lowland. So, those three classes of the basin exhibited different precipitation and temperature trends.

The basin had 1019.41mm mean rainfall in the study time series. It got mean maximum rainfall 1339.78mm in 1993 and mean minimum rainfall 872.76mm during 1997. From the study station, maximum rainfall recorded is observed at Sebata station 3131.10mm by 1993. The Hombole station is the least rainfall recorded station 211.07mm by 1994.

The highland area meteorological evaluation resulted in an increasing and decreasing trend with both precipitation and temperature. Furthermore, during *Gann* a season with Addis Ababa, Addis Alem and Sendafa got increasing except Sendafa station; while decreasing trend observed during the Arfaasaa season and annually within all stations except Sendafa. Likewise, Addis Ababa station that considered as the temperature representative of the highland area got increased from both maximum and minimum temperatures. Midland stations revealed a decreasing trend in precipitation with seasonal change of temperature. The lowland area resulted in an increasing trend of precipitation with all stations except the Birraa season of Mojo station. Similarly, this part of the basin got an increasing trend of temperature.

The Mojo river sub-basin got a decreasing trend of streamflow except for*Ganna* season. The Awash-Hombole sub-basin got decreasing annually except Berga and Melka kunture streamflow. During *Ganna* season, Awash Balo, Berga, and Melka Kunture exhibited an increasing trend while the rest got decreased.

Generally, the basin got maximum rainfall 1339.78mm in 1993 and minimum rainfall 872.76mm in 1997. Similarly, the basin maximum streamflow 39.4 by 1996 and minimum streamflow 9.92 m^3/s in 2002. Precipitation of the basin increased annually and during the*Arfaasaa* season with 30% of study stations (Mojo, Sendafa, and Asgori) only. The rest 70% of them exhibited a decreasing trend. But stations are insignificantly increasing while Ejere and Sebata decreasing insignificantly. *Ganna* seasons precipitation of study stations revealed 50% both increasing and decreasing trend. Similarly, basin streamflow exhibited change. Mojo's main tributary is gauged at Mojo station and it resulted in a decreasing trend in wet seasons ad annually. During *Arfaasaa, Ganna* and *Birraa* seasons the tributary decreased. Annually and in the *Birraa* season, it decreased significantly at 90% and 95% significance level respectively.

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Data sharing

The data that support the findings of this study are available from National Meteorology Agency. Restrictions apply to the availability of these data, which were used under license for this study. Data are available http://www.ethiomet.gov.et with the permission of National Meteorology Agency.

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SN	Station	Longitude	Latitude	Elevation(M)	Missing	Missing %
1	Addis Ababa	38.75	9.02	2386	1	0.24
2	Addis Alem	38.38	9.042	2372	6	1.41
3	Asgori	38.33	8.79	2072	15	3.53
4	Ejere	39.27	8.77	2254	28	6.59
5	Bishoftu	38.95	8.73	1900	10	2.35
6	Ginchi	38.13	9.02	2132	5	1.18
7	Hombole	38.77	8.37	1743	60	14.12
8	Kimoye	38.34	9.01	2150	3	0.71
9	Mojo	39.11	8.61	1763	10	2.35
10	Sebata	38.63	8.92	2220	19	4.47
11	Sendafa	39.02	9.15	2569	51	12.00

Table 1. Precipitation stations with their missing values

SN	Station name	Longitude	Latitude	Area (sq. km)	Period
1	Akaki	38.47	8.53	884.4	1991 – 2009
2	Awash Ballo	38.41	8.85	2568.8	1991 – 2012
3	Berga	38.21	9.10	248	1991 – 2012
4	Holota	38.51	9.08	316	1991 – 2011
5	Melka Kunture	38.36	8.42	4456	1991 – 2015
6	Mojo	39.50	8.36	1264.4	1991 – 2015
7	Hombole	38.47	8.23	7656	1991 – 2015

Table 2. streamflow gauging stations

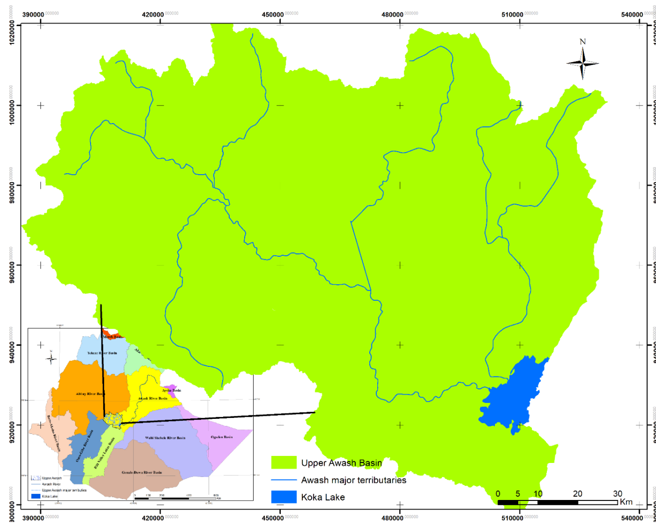
Station	Season	S-Value	P-value	Z-value	Sen's Slope	CV %
Addis Ababa	Arfaasaa	-34	0.392	-0.864	-0.781	38.99
	Ganna	36	0.418	0.817	0.851	12.73
	Annual	-14	0.764	-0.303	-0.201	14.57
Addis Alem	Arfaasaa	-24	0.595	-0.537	-0.315	33.36
	Ganna	32	0.442	0.769	0.959	55.63
	Annual	-98	0.023	-2.26	-1.028	17.03
Bishoftu	Arfaasaa	50	0.25	1.14	0.96	54.9
	Ganna	52	0.23	1.19	1.15	20.56
	Annual	66	0.13	1.52	7.27	18.1
Ejere	Arfaasaa	-36	0.414	-0.817	-0.784	47.25
	Ganna	-132	2.17	-3.06	-3.267	18.27
	Annual	-84	0.052	-1.938	-0.975	15.78
Ginchi	Arfaasaa	-34	0.441	-0.771	-0.825	46.75
	Ganna	-16	0.726	-0.35	-0.634	25.76
	Annual	-28	0.528	-0.631	-0.311	22.98
Hombole	Arfaasaa	0	0.981	0	4.861	78.39
	Ganna	-68	0.117	-1.564	-2.027	39.8
	Annual	-6	0.907	-0.117	-0.018	39.64
Kimoye	Arfaasaa	-10	0.833	-0.21	-0.296	41.85
	Ganna	-18	0.691	-0.397	-0.18	11.18
	Annual	-10	0.833	-0.21	-0.047	24.64
Mojo	Arfaasaa	46	0.293	1.051	0.89	62.84
	Ganna	36	0.414	0.817	1.676	35.34
	Annual	66	0.129	1.518	0.747	27.28
Sebata	Arfaasaa	-29	0.313	-0.654	-0.85	67.87
	Ganna	-4.84	0.009	-2.6	-3.041	45.9
	Annual	-86	0.035	-2.11	-1.124	43.85
Sendafa	Arfaasaa	2	0.981	0.0233	0.033	64.77
	Ganna	88	0.042	2.031	2.861	21.93
	Annual	52	0.233	1.191	0.556	14.45
Asgori	Arfaasaa	55	0.207	1.262	0.63	51.35
	Ganna	70	0.107	1.611	1.84	16.49
	Annual	48	0.272	1.097	0.349	17.55

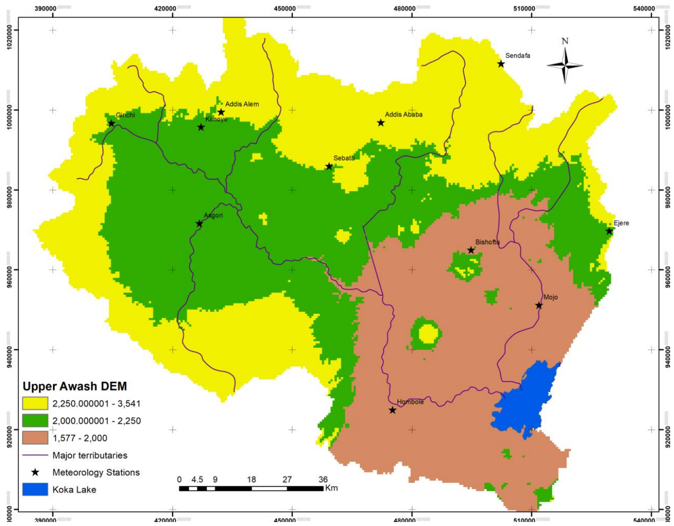
Table 3. Trend analysis result of Precipitation.

Station	Season	S-Value	P-value	Z-value	Sen's Slope	CV %
Akaki	Arfaasaa	-25.00	0.363	-0.909	-0.097	105.51
	Ganna	-69.00	0.016	-2.379	-2.321	86.33
	Birraa	-95.00	0.006	-3.289	-1.053	99.23
	Bona	-47.00	0.081	-1.742	-0.158	111.56
	Annual	-55.00	0.041	-2.045	-0.839	82.33
Awash Ballo	Arfaasaa	-63.00	0.080	-1.748	-0.034	81.47
	Ganna	97.00	0.007	2.707	0.492	18.43
	Birraa	71.00	0.048	1.974	0.252	24.42
	Bona	-143.00	0.014	-2.446	-0.021	44.60
	Annual	75.00	0.037	2.087	0.143	17.31
Berga	Arfaasaa	48.00	0.156	1.419	0.026	86.04
	Ganna	67.00	0.063	1.861	0.203	39.40

Station	**Season**	**S-Value**	**P-value**	**Z-value**	**Sen's Slope**	**CV %**
	Birraa	55.00	0.128	1.523	0.081	81.25
	Bona	-20.00	0.959	-0.030	-0.004	194.24
	Annual	77.00	0.032	2.143	0.097	54.22
Holota	Arfaasaa	2.00	0.976	0.030	0.001	45.10
	Ganna	-4.00	0.928	-0.091	-0.002	29.99
	Birraa	-20.00	0.566	-0.574	-0.027	53.10
	Bona	34.00	0.319	0.996	0.004	57.67
	Annual	-24.00	0.487	-0.694	-0.010	33.01
Melka Kunture	Arfaasaa	27.00	0.543	0.607	0.143	70.52
	Ganna	69.00	0.112	1.59	1.307	28.43
	Birraa	9.00	0.851	0.187	0.122	31.32
	Bona	-40.00	0.333	-0.967	-0.0131	24.25
	Annual	51.00	0.243	1.168	0.323	26.86
Hombole	Arfaasaa	52.00	0.233	1.191	0.123	48.96
	Ganna	-46.00	0.293	-1.051	-1.047	31.72
	Birraa	14.00	0.761	0.304	0.249	33.79
	Bona	38.00	0.359	0.918	0.024	21.52
	Annual	-24.00	0.591	-0.537	-0.173	27.95
Mojo	Arfaasaa	-14.00	0.761	-3.036	-0.14	372.31
	Ganna	-56.00	0.172	-1.364	-0.483	104.10
	Birraa	-122.00	0.0471	-2.825	-0.0839	165.44
	Bona	58.00	0.183	1.331	0.005	461.97
	Annual	-72.00	0.078	-1.761	-0.302	137.47

Table 4. Trend analysis result of Streamflow


390000
420000
450000
480000
510000
540000
1020000
1000000
980000
960000
940000
920000
900000
N
Upper Awash Basin
Awash major terributaries
Koka Lake
0 5 10 20 30
Km


390000
420000
450000
480000
510000
540000
1020000
1000000
980000
960000
940000
920000
N
Sendafa
Addis Alem
Ginchi
Kimoye
Addis Ababa
Sebata
Asgori
Ejere
Bishoftu
Mojo
Hombole
Upper Awash DEM
2,250.000001 - 3,541
2,000.000001 - 2,250
1,577 - 2,000
Major terributaries
Meteorology Stations
Koka Lake
0 4.5 9 18 27 36
Km

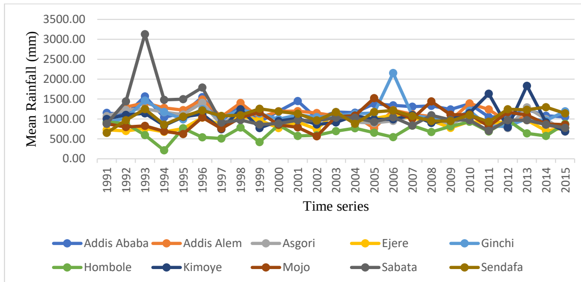
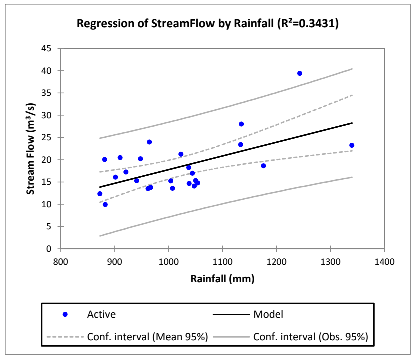

3500.00
3000.00
2500.00
2000.00
1500.00
1000.00
500.00
0.00
Mean Rainfall (mm)
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Time series
Addis Ababa
Addis Alem
Asgori
Ejere
Ginchi
Hombole
Kimoye
Mojo
Sabata
Sendafa

Figure 3



Regression of StreamFlow by Rainfall (R²=0.3431)
Stream Flow (m³/s)
Rainfall (mm)
0
5
10
15
20
25
30
35
40
45
800
900
1000
1100
1200
1300
1400
Active
Model
Conf. interval (Mean 95%)
Conf. interval (Obs. 95%)

Figure 4