International Journal of Scientific & Engineering Research, Volume 11, Issue 1, January-2020
ISSN 2229-5518

Rainfall and Flood Event Interrelationship - A Case Study of Awash and Omo-Gibe Basins, Ethiopia

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Abstract— Flood is one of the natural hazards that often occurs due to extreme flows. Flood impacts have become more precarious in flood vulnerable areas as people concentrate near floodplains seeking the benefits of proximity to water bodies. In Ethiopia, like other locations around the globe, the need to living near to water and fertile land has intensified flood risk. This study was therefore aimed to evaluate rainfall and its capacity to trigger flooding in the Awash and Omo-Gibe basins using statistical methods and ArcGIS tools to evaluate the Spatio-temporal relationship between rainfall and flood occurrences. Results showed that four weather stations in the Awash basin and four in the Omo-Gibe basin showed modest to increasing rainfall which signifies an increasing likelihood of flooding. In contrast, four other weather stations in the Awash basin and one Omo-Gibe basin showed decreasing trends that indicate less probability of flooding. The Standardized Precipitation Index (SPI) values also showed in agreement probable flood events. The results also indicate that heavy rainfall events triggered peak runoff contributing to 1996, 1998, 2006 and 2016 flood events. Understanding this relationship between rainfall and flooding risk will provide a solid foundation for flood forecasting in these two basins. Therefore, this study will support decision-makers in the process of development planning and strategies.

Keywords— Flooding, rainfall, SPI, statistical-analysis, Ethiopia.

◆

1 INTRODUCTION

Climate change is one of the prime threats to humanity and the environment [1]. Many research findings on climate change have been indicated that the frequency of extreme rainfall events and subsequently flooding [2] and [3] are increasing. Extreme and high-intensity rainfall events are expected to increase in the future [1] and [4], particularly at mid and high latitudes, such as Ethiopia. In addition to rainfall events, the characteristics of hydrological systems, such as catchment size, landscape, land use, topography, and soils often play significant roles in triggering flood risks. The impact of climate change on water resources variability, especially on river flows [5], [6], [7], [8] and [9], soil moisture and land cover dynamics [10], [11] and [12], evapotranspiration, and groundwater flow has been thoroughly studied using projected and downscaled climatic data and hydrological models.

In Ethiopia, the impact of climate change on precipitation in the last 50 years appears variable and less predictable [13], and the temperature has increased at about 0.2°C per decade [14]. Therefore, rainfall plays a significant role in the study of floods and water planning and management systems [15]. The Spatio-temporal trends and patterns of rainfall [16] and [17] help to develop flood mitigation measures and evaluation of the ecosystem resilience towards such variability [18]. Practically reliable representation of areal rainfall data derived from point rainfall observations [19] used to study flood impacts and hydrological modeling. In many developing countries, rain observation data are often scaring, unevenly distributed, and temporally inconsistent [20], which necessitates the use of alternative remotely-sensed rainfall data in hydrological analyses. Commonly, satellite-based rainfall data have even distribution, high-resolution coverage, and can support analysis on hydrological processes and flood modeling by augmenting observation data. The spatially extensive satellite-derived rainfall estimates are often desirable to blend with rain gauge observations to study the state of trends, particularly in areas with minimal observation data [21]. This study aims to; (1) compare the satellite-driven rainfall products with ground measurements, (2) analyze rainfall trends and variability in time and space, and (3) study the interrelationship of rainfall and runoff outcomes of flooding in the study basins.

1.1 Study Area and Data

1.1.1 Study area

Ethiopia is geographically located in the Horn of Africa between 3°and 15°N latitudes and 33° and 48°E longitudes. The country is divided into two escarpments by the Great Rift Valley (GRV) and its highest elevation is Ras Dejen (4550 m) in the Semien Mountains and the lowest elevation in the Afar Depression at -125 m below sea level. The total area of the country is 1.13 million km^2 of which approximately 99% is landmass and the remaining is covered by water bodies. Ethiopia has twelve river basins of which eight basins are wet river basins, one lakes basin, and three dry river basins.

Awash and Omo-Gibe basins are 2 of the 8 wet basins in the country, which are selected to explore climate-induced heavy rainfall events since the flood-prone areas of these basins are

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highly affected by recurrent flooding. The impacts are heavy due to the fact that these basins are highly populated and intensive developments. The Awash Basin is located between 8°8' and 9°23'N latitudes and 37°57' and 39°E longitudes in the north-eastern part of the country with a total catchment area of 114,123 square kilometers. The Omo-Gibe basin is located between 4°45′ and 9°22′N latitudes and 34°50′and 38°25′E longitudes which are in the south-western part of the country with a total catchment area of 77,826 square kilometers. Both basins are located in the GRV (Fig. 1) however, the climatology of the two basins is vastly different [22] and [23].

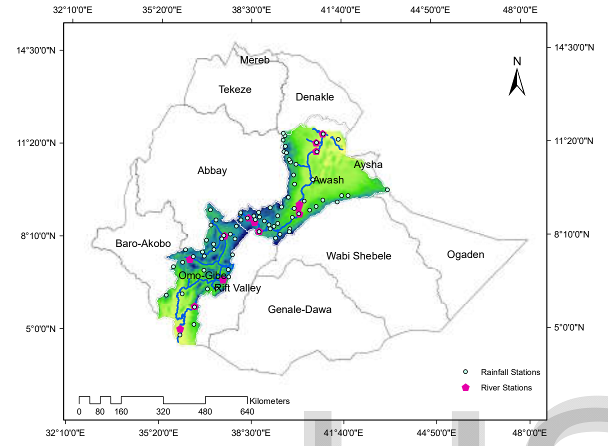


Fig. 1. Location of Awash and Omo-Gibe basins, rainfall stations, and streamflow gaging, and elevation gradient

1.1.2 Data used

Observed weather station data from National Meteorological Agency (NMA) of Ethiopia and satellite-derived rainfall product of Climate Hazard Group Infra-Red Precipitation with Stations (CHIRPS) from National Centers for Environmental Prediction (NCEP), and river flows from Ministry of Water, Irrigation and Energy (MoWIE) of Ethiopia were used for the analysis.

The rainfall observation data from 49 weather stations in the Awash Basin and the 28 weather stations in the Omo-Gibe Basin were collected. Nevertheless, 8 weather stations in the Awash and 5 stations in the Omo-Gibe basins with superior consistency (< 2% missing data) and overall data quality was used to verify the satellite-derived rainfall data [24].

Table 1 Observed rainfall stations used to verify CHIRPS

S.N.	Awash Basin		
	Rainfall Stations	Mean annual rainfall (mm)	Missing data (%)
1	Addis Ababa	1038.8	0.3
2	Akaki	987.9	0.6
3	Ginchi	1134.7	1.1
4	Gurand-Meta	980.0	1.1
5	Haik	1168.0	1.4
6	Combolcha	1010.2	0.3
7	Metehara	513.9	-
8	Shola-Gebeya	1077.0	1.7
	Omo-Gibe Basin		
9	Assendabo	1108.1	1.3
10	Gibe Farm	917.4	1.9
11	Jima	1504.4	-
12	Wolaita-Sodo	1243.7	1.7
13	Wolkite	1268.5	0.8

CHIRPS rainfall data is developed by the United States Geological Survey (USGS) and the National Climate Forecast System. It is a blended product combining pentad precipitation climatology, quasi-global geostationary satellite observations from the climate prediction center [2]. In tropical arid areas, CHIRPS can be a good alternative source for rain gauge precipitation data. It is blended with 208 quality-controlled gauge observations from NMA using the GeoCLIM tool to generate monthly 1981-2016 grids of precipitation [25]. [25] compared the average of the blended CHIRPS/NMA station data to the CHPclim, GPCC, CRU, and Worldclim datasets. The Climate Hazards Group's Precipitation Climatology (CHPclim) is, therefore, used in the CHIRPS as background climatology which is dependent on the NMA datasets.

In this analysis, some river gauging stations were selected in each of the two river basins and were used as control stations. The river gauging stations in the Awash Basin are Awash River at Melka-Belo, Melka-Kuntire, Melka-Hombole, 7-Kilo, Melka-Sedi, Melka-Werer, Mile, Logia and Adaitu. Similarly, the Great Gibe river at Abelti, Gogera, Gojeb, Neri, and Omo at Omorate River gauging stations in the Omo-Gibe Basin (Fig. 2). Therefore, the contribution of rainfall events has been used to compare and analyze its correlation with the corresponding peak river flood flows at these river gauging stations.

Digital Elevation Models (DEM) with 30-meter resolution from Shuttle Radar Topography Mission (SRTM) space center was also used in this analysis. The DEM data was used to illustrate the physical characteristics of the basins, such as topographic features, elevation, and rainfall distributions.

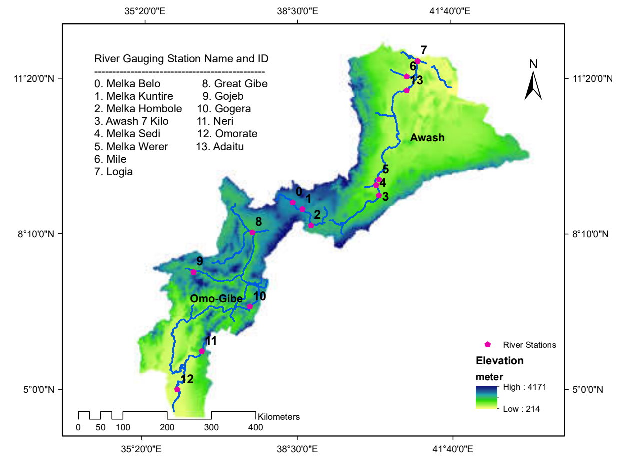


Fig. 2. River gauging stations in Awash & Omo-Gibe basins

2 METHODS

2.1 Statistical Analyses

Observed rainfall data for the period of 1981 to 2016 was evaluated and compared with the CHIRPS dataset to fill rainfall data gaps and produce reliable input data to analyze flood processes and modeling. Point-to-point and point-to-pixel statistical validation of CHIRPS over the study area with a daily time step (for 36 years of records) were used to compute long-term rainfall analysis. A similar statistical analysis was performed [26]. Commonly used statistical techniques, such as correlation coefficient (r) or the coefficient of determination (R^2), Nash–Sutcliffe Efficiency [27], Mean Error (ME), and Root Mean Square Error (RMSE) were applied. These statistical methods were selected and used since their usage is simple and efficient to assess the performance of the models. Bias correction was also used to correct the raw satellite data using the differences in the mean and variability between satellite rainfall and observations [28]. If a Bias value approaches 1, it indicates good results and the cumulative values of both observed and satellite rainfall data are closer to each other.

Therefore, once the rainfall data were ready, the analysis of rainfall trends and its significance to flooding events, the non-parametric Mann-Kendall test was adopted [29] and [30]. It helps to detect significant hydro-meteorological time series trends [31]. The Mann-Kendal test was also used to show how CHIRPS behaves compared with observed rainfall data at a 5% significance level [32] and [33].

2.2. Evaluation of Spatio-Temporal Rainfall Variations

The long-term rainfall records were employed in the analysis to identify the Spatio-temporal classification of wetness of seasons (June to September). Standardized Precipitation Index (SPI), which is a widely used classification technique [34] and [35], was adopted to categorize the probability of occurrence of precipitation based on the longer time scale (1981-2016) rainfall records. The SPI index values were computed to classify wetness and dryness (Table 2)

Table 2 Wetness and dryness classifications of based on SPI values

SPI values	Flood Classification
>=2.0	Extreme wet (Big flood)
1.5 to 1.99	Severely wet (Rigorous flood)
1 to 1.49	Moderate wet
0 to 0.99	Near normal
< 0	No flood (Dry)

2.3 Evaluation of Rainfall and Runoff Interrelationship

The Spatio-temporal rainfall distributions and its interrelationship with peak runoff were assessed using the SPI [34] and [36] and the amount of rainfall. Similarly, the spatial distribution of both rainfall and runoff and their relationship over the two basins were examined. In the analysis, a geostatistical tool of Kriging interpolation technique [37] in ArcGIS was utilized. Kriging is an efficient interpolation technique that produces spatial information from point data which interpolates data to areas where actual data were not available. Therefore, the rainfall events in the catchment that induced runoff at a given river gauging stations were identified and analyzed to visualize the spatial distributions interpolated values and their interrelationships.

The comparative analyses between rainfall and the corresponding runoff events were performed for the identified flood years of 1996, 1998, 2006, 2010 and 2016 in the two river basins. The interrelationship of rainfall and runoff was further analyzed using peak rainfall events and peak streamflow (Fig. 9 and Fig. 10), especially in the flood-prone areas. In this context, the likelihood of flooding increases as the amount of rain at a specific location increases both in intensity and duration [32]. The contribution of rainfall has also been compared statistically with the peak runoff at the identified river gauging stations for the prominent flooding event cycle (e.g., decadal cycle), such as 1996, 2006 and 2016 flood years.

Five locations were identified three in the Awash Basin, namely the upper, middle and lower sub-basins, and two in the Omo-Gibe basin, namely upper and lower sub-basins to evaluate the temporal and spatial interrelationship analysis of rainfall and runoff and its contribution to flooding. These locations are Awash river at Melka-Belo, at Melka-Kuntire and at Melka-Hombole in the upper sub-basin; Awash river at 7-Kilo, at Melka-Sedi and at Melka-Werer in middle sub-basins; and Awash river at Adaitu, Mile at Mile and Logia at Logia river gauging stations in the lower sub-basin of Awash basin. Similarly, the Great Gibe river at Abelti, Wabi near Wolkite and Gojeb near Shepe river gauging stations in upper- and Omo river at Omorate and Neri at Jinka in lower- sub-basin of Omo-Gibe basin.

3 RESULTS AND DISCUSSIONS

3.1 Rainfall Evaluation

CHIRPS rainfall estimate was evaluated for the spatial and temporal conditions at daily, monthly, and seasonal time steps using rainfall observation data and the correlations with the induced peak river flood flows are described below.

3.1.1 Monthly comparison

The monthly comparison of satellite-driven rainfall data with observed rainfall data was carried out using the 13 selected weather stations (Fig. 3) with good rainfall data. The overall performance of the statistical methods using NSE, r, R^2, ME, RMSE, and Bias correction is presented in Table 3. Based on the result, some of the weather stations with missing data were filled with CHIRPS rainfall data before it was used for further analysis. The gap-filling of rainfall for Addis Ababa weather station was maintained for instance, since the NSE, r, and R^2 values closer to 1; 0.806, 0.992, and 0.880 respectively. If seeing individual value, the techniques perform very similarly, although to differing degrees, the r values for all identified weather stations exceeding 0.89 (Table 3).

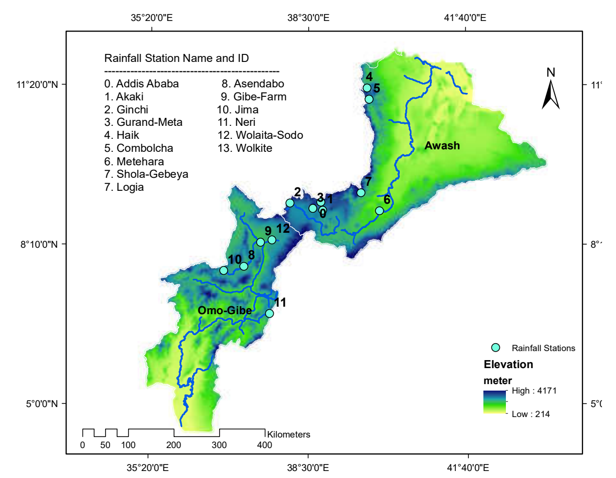


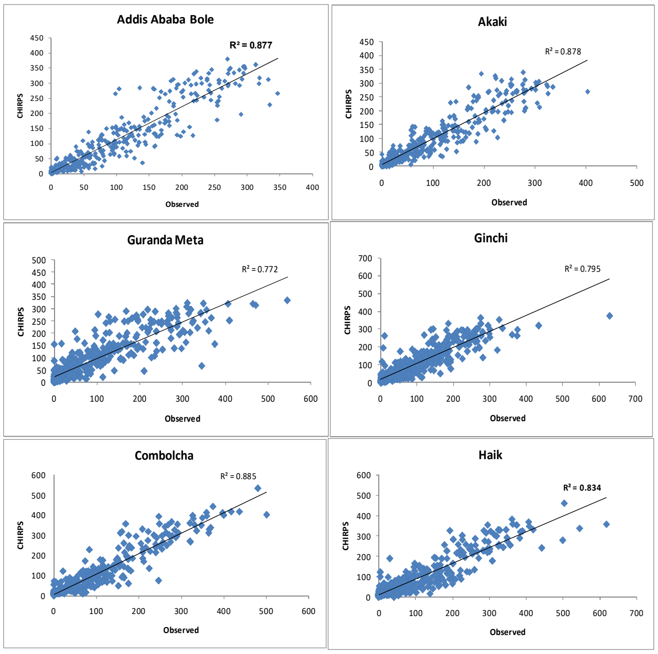
Fig. 3. The spatial location of the selected weather stations

Table 3 Statistical parameters for monthly observed and CHIRPS rainfall data

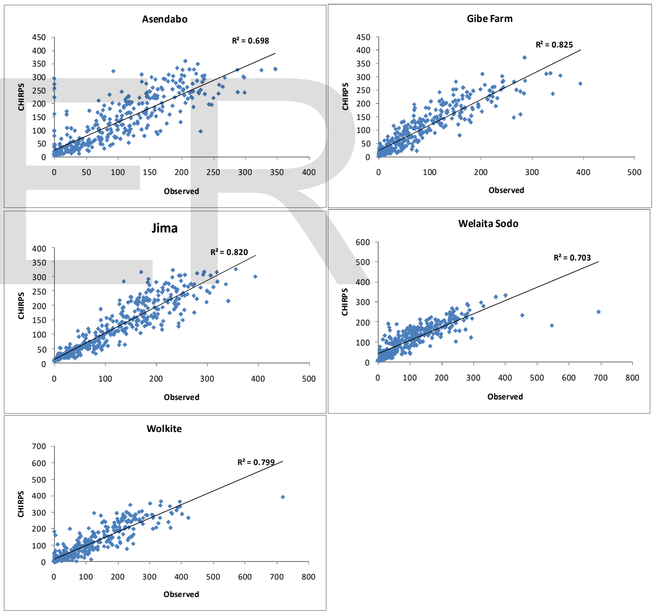
Basins	St. ID	Rainfall Stations	NSE	r	R²	ME	RMSE	Bias
Awash Bain	0	Addis Ababa	0.806	0.992	0.880	10.5	38.2	1.120
	1	Akaki	0.875	0.991	0.887	0.4	30.9	1.004
	2	Ginchi	0.805	0.990	0.823	5.4	41.0	1.056
	3	Gurand-Meta	0.811	0.988	0.787	5.4	41.0	1.046
	4	Haik	0.783	0.966	0.843	3.9	46.8	0.854
	5	Combolcha	0.569	0.897	0.626	17.4	65.0	1.203
	6	Metehara	0.772	0.960	0.796	3.9	22.8	1.089
	7	Shola-Gebeya	0.733	0.987	0.825	-15.6	57.7	0.809
Omo-Gibe Basin	8	Asendabo	0.515	0.966	0.769	27.7	54.7	1.277
	9	Gibe farm	0.750	0.988	0.830	18.8	39.0	1.237
	10	Jimma	0.809	0.992	0.820	2.2	37.8	1.017
	11	Wolaita-Sodo	0.692	0.962	0.700	6.9	50.9	1.065
	12	Wolkite	0.807	0.983	0.808	-2.6	46.5	0.976

The monthly performance of the determination coefficient (R^2) between the satellite and the observed rainfall data for the period of 1981-2016, for instance, is presented in

Table 3 and the values range between 0.62 and 0.88. Moreover, the Bias values for almost all selected sample stations were closer to 1, which indicates that the observed and CHIRPS rainfall data were relatively closer. Similar statistical validation of CHIRPS over Ethiopia was also validated with 0.75 NSE [21] and [28]. Nonetheless, the NSE for Combolcha (0.569) and Asendabo (0.515) weather stations showed lower values compared to Akaki (0.875). The reason might be due to the data quality they possess, which will require further analysis in the future.



a/ Rainfall in the Omo-Gibe Basin

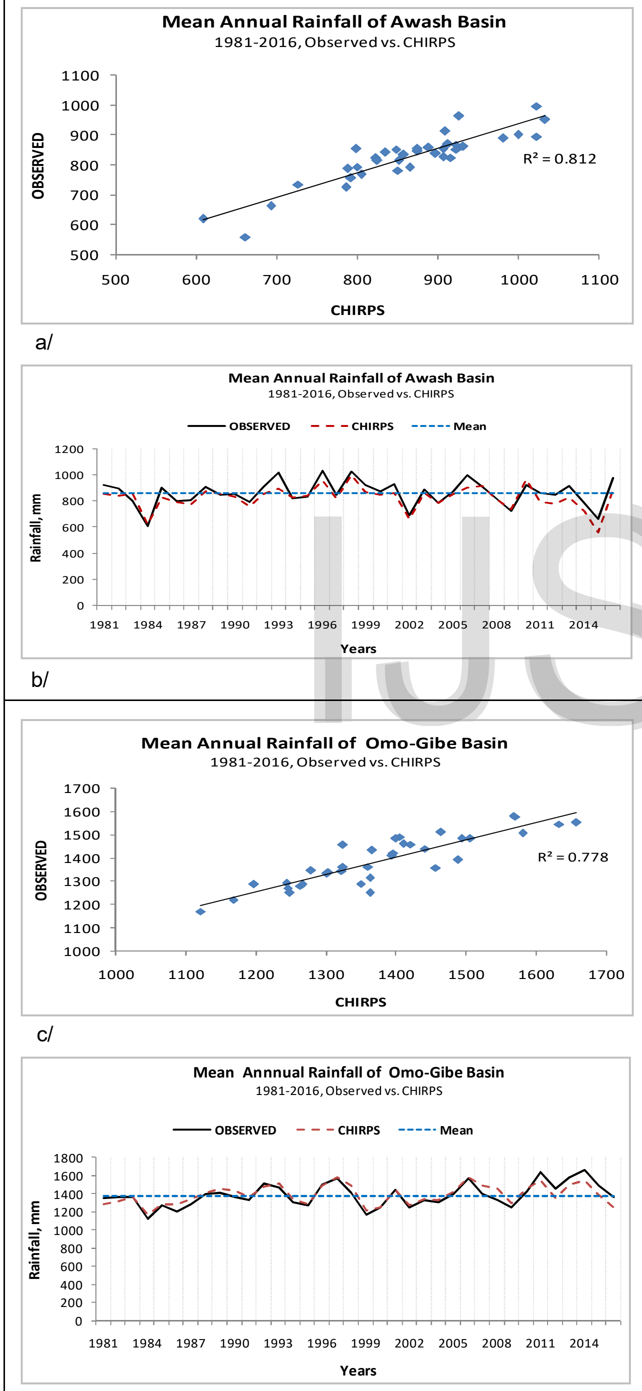


b/ Rainfall in the Omo-Gibe Basin

Fig. 4. Monthly observed rainfall (mm) vs. CHIRPS

3.1.2 Annual comparison

The mean annual rainfall data were calculated from the daily rainfall data for selected and representative rainfall gauging stations. The statistical performances for the Awash and Omo-Gibe basins using R^2 obtained were 0.81 and 0.78, respectively. Based on the assessment of historical records and maximum rainfall distributions, 1993, 1996, 1998, 2006, 2010, and 2016 in the Awash Basin, and 1992, 1996, 1997, 2006, 2011 and 2014 in the Omo-Gibe Basin were identified as flood years. The results indicate that the CHIRPS dataset performs well in replicating observed rainfall for the two basins with a slight underestimation for the Awash Basin (Fig. 5 b/) and a slight overestimation for Omo-Gibe basin (Fig. 5 d/) over the mean. The magnitude of rainfall overestimation in the Omo-Gibe Basin is due to its mountainous topographic nature, unlike the Awash Basin. Moreover, in the Awash Basin, there was one outlier occurred in the year 2015 (Fig. 5 a/ which falls far below the regression line indicating the different characteristics of the station. In contrast, there were no significant outliers observed in the Omo-Gibe Basin (Fig. 5 c/).



a/

b/

c/

d/

Fig. 5. Annual rainfall comparisons in the Awash and Omo-Gibe basins

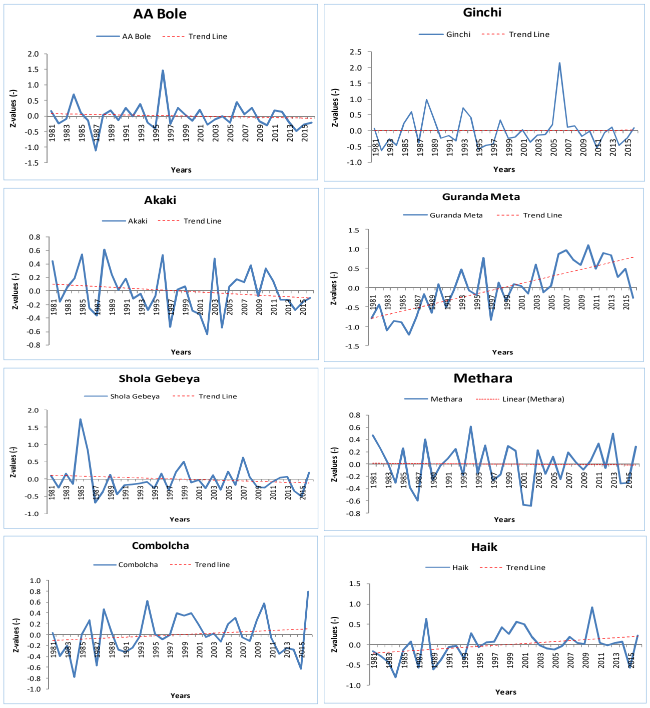
3.1.3 Rainfall trends

The long-term annual rainfall indicates an increasing trend with varying from 608 mm in the year 1984 to 1032 mm in the year 1996 (41%) in the Awash Basin and 1120 mm in the year 1984 to 1657 mm in the year 2014 (32%) in Omo-Gibe basin. In addition, the z-values (Fig. 6) showed increasing rainfall trends for a few of the stations in the two basins such as Ginchi, Gurand-Mata, Combolcha, and Haik weather stations for the Awash Basin and Asendabo and Gibe-Farm weather stations for the Omo-Gibe Basin. On the other hand, some weather stations, such as Akaki and Shola-Gebeya in the Awash Basin and Wolkite in the Omo-Gibe Basin showed decreasing trends. Apart from the increasing or decreasing trends, some weather stations, such as Addis Ababa, Ginchi, Metehara, Jima and Welaita-Sodo weather stations did not show significant trends (Fig. 6).

3.2 Temporal and Spatial Assessment

3.2.1 Temporal assessment

The time series plots that demonstrate the bias-corrected data for the 4 rainy season months (June, July, August and September, (JJAS)) of z-values are presented in Fig. 6. The higher z-values of the temporal assessment at Ginchi (2.2), Shola-Gebeya (1.7), Addis Ababa (1.5), and Gurand-Meta (1.1) weather stations in the Awash Basin indicate greater rainfall; and Welaita-Sodo (3.1), Wolkite (1.8) and Gibe farm (1.4) in the Omo-Gibe Basin (Table 4). Moreover, Ginchi, Gurand-Meta, Haik, Kombolcha, Asendabo, Gibe-farm, Wolatita-Sodo, and Jima weather stations showed statistically modest to significant increases in trends, -0.0058 for Akaki as modest to 0.0452 for Gurand-Meta as significant increase based on trend slope (Fig. 6). The increasing trend of rainfall indicates that the greater probability of flood occurrence, especially on respective flood susceptible areas. The likelihood of flooding increases as the amount of rain at a given location increases [38] both in intensity and duration when the ground surface is saturated enough to absorb the excess amount of floodwater. Therefore, results indicate that there is a greater probability of occurrences of substantial flooding events that range from rigorous floods between 1.5 and 2 to the big floods greater than 2 in flood-prone areas (Table 2).



a/ Z-Values in the Awash Basin

b/ Z-Values in the Omo-Gibe Basin

Fig. 6. Plots of rainfall (z-values) for 4-months (JJAS) for selected stations in the Omo-Gibe Basin

Table 4 Index of weather stations showing z-values for 1981-2016

S.N.	Rainfall stations	Z-values (-)	
	Awash Basin		
		Min	Max
1	Addis Ababa	-1.1	1.5
2	Akaki	-0.6	0.6
3	Combolcha	-0.8	0.8
4	Ginchi	-0.6	2.2
5	Gurand-Meta	-1.2	1.1
6	Haik	-0.8	0.9
7	Metehara	-0.7	0.6
8	Shola-Gebeya	-0.7	1.7
	Omo-Gibe Basin		
9	Asendabo	-1.1	1.2
10	Gibe Farm	-0.7	1.4
11	Jimma	-1.5	1.3
12	Welaita-Sodo	-1.3	3.1
13	Wolkite	-1.1	1.8

3.2.2 Spatial assessment

The spatial rainfall distributions over the two basins were analyzed and extracted using the Kriging geostatistical analysis tool [37]. Based on this analysis, rainfall showed a considerable increase from the north-east part of the Awash Basin to the south-western and central highlands of the Omo-Gibe Basin Fig. 7). The magnitude of the mean annual rainfall was highly variable and can be as low as 200 mm in the eastern part of the Awash Basin and to a maximum of up to 2000 mm at central highlands of the Omo-Gibe Basin.

The spatial rainfall distribution that corresponds to the attributes of the climatic zones of Ethiopia [22], has bimodal behavior (Fig. 6 a/) in the Awash Basin and mono-modal behavior (Fig. 6 b/) in the Omo-Gibe Basin. Distinct seasonal patterns appear between the central and western parts of the Omo-Gibe Basin and the north-eastern part of the Awash Basin due to different influences from the different influence of teleconnection patterns on rainfall distributions [39]. In general, the spatial distribution of rainfall, especially where maximum rainfall events are observed, has contributed to the increased probability of flooding occurrences in most flood-prone areas.

3.3 Rainfall and Runoff Interrelationship

3.3.1 Temporal interrelationship

Analyses were conducted to better understand peak rainfall and its contributions to and temporal interrelationship with peak runoff, as well as outcomes of a flooding event. Consequently, representative weather stations that have closer interrelationship to runoff at the selected river gauging stations were identified. Thus, in the upper Awash sub-basin; Addis Ababa, Akaki, Busa, Boneya, Debrezeit, Dertu-Liben, Ginchi, Gurand-Meta and Teji weather stations were identified. In the middle Awash sub-basin; Aleltu, Aliyu-Amba, Arerti, Shola-Gebeya, Abomisa, Teferi-Birhan, Awara-Melka, Metehara and Awash 7-Kilo weather stations, and in the lower Awash sub-basin; Chefa, Combolcha, Bora, Gewane, Mersa, Adaitu, Mile and Dubti weather stations have been identified. Similarly, Limu-Genet, Busa, Asendabo, Baco, Seyo, Algae, Kumbi, and Gibe-Farm weather stations contributed to the runoff for the Great Gibe river at Abelti, Wabi near Wolkite river gauging stations in the upper Omo-Gibe sub-basin. Jinka, Dimeka, Hana, Maji and Omorate weather stations contributed to the runoff of the Omo river near Omorate gauging station.

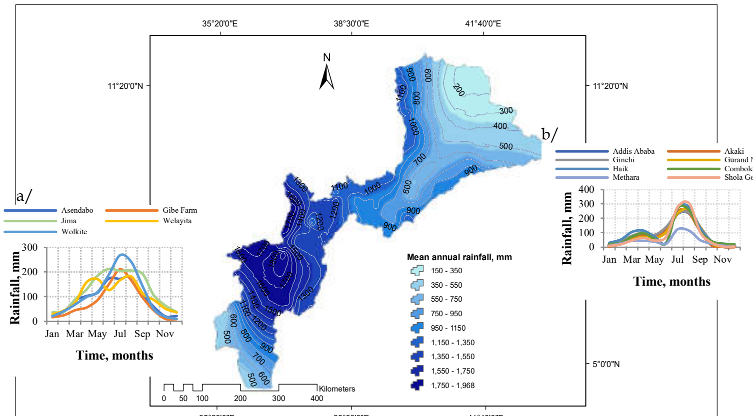
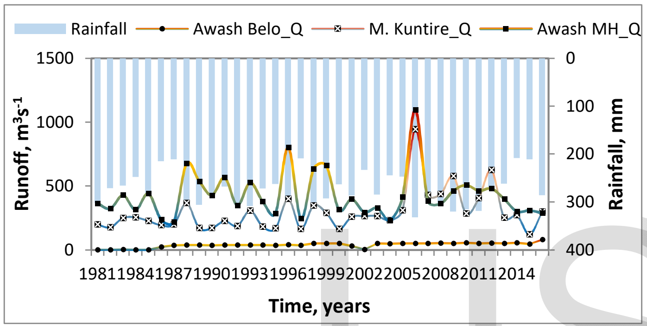
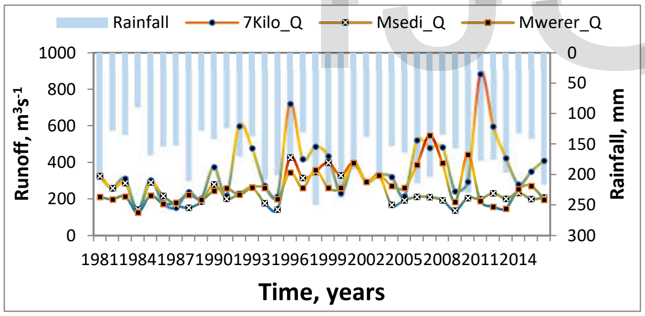


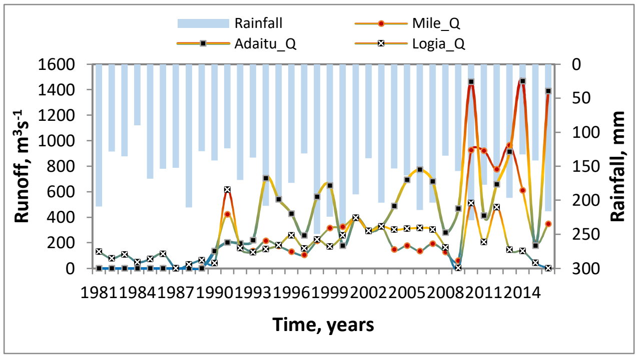
Fig. 7. Spatial variability of mean annual rainfall (mm) in Awash and Omo-Gibe basins



a/ Awash at Belo, M. Kuntire and M. Hombole river gauge stations

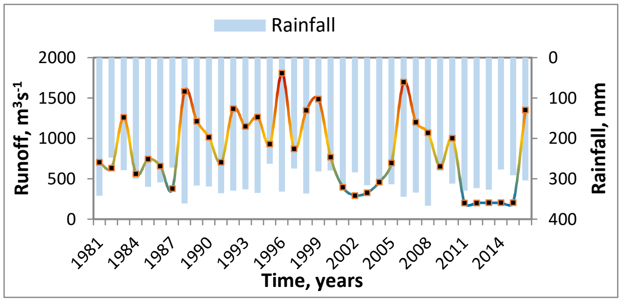


b/ Awash river at 7 Kilo, M. Sedi and M. Werer gauging stations

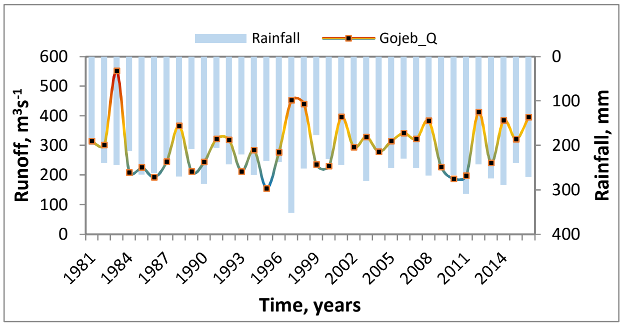


c/ Awash river at Adaitu, Mile and Logia gauging stations

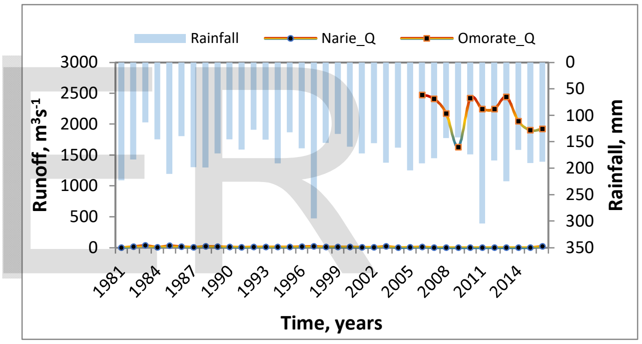
Fig. 8. Rainfall and runoff interrelationship plots (a, b and c) in the Awash Basin



a/ Great Gibe at Abelti river gauging station



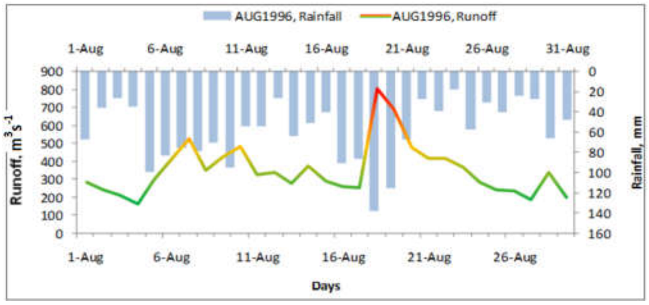
b/ Gojeb near Shebe river gauging station



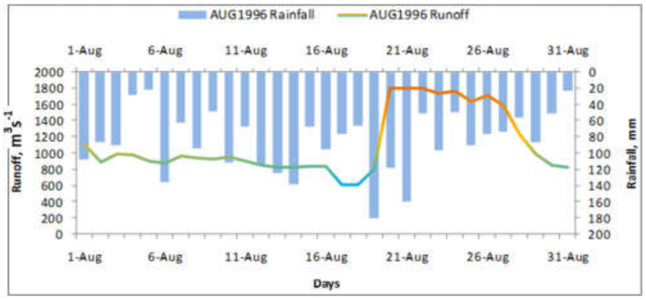
c/ Omo near Omorate and Nerie at Jinka river gauging stations

Fig. 9. Rainfall and runoff interrelationship plots (a, b and c) in the Omo-Gibe Basin

According to the hyetograph and hydrograph plots (Fig. 7) and the statistical analysis, rainfall showed correlations at the identified river gauging records for the identified flood years. This interrelationship of peak rainfall to peak runoff was likely the basis for the occurrences of flooding for the1996, 1998, 2006, and 2016 flood years. Moreover, the daily peak river flows of the Awash river at M. Hombole and Great Gibe river at Abelti gauging stations were evaluated and showed a correlation value of R^2 equals to 0.9131 with the corresponding rainfall. This correlation indicated that the catchment response to peak rainfall is quicker and resulted in peak runoff on the 20th of August 1996 (Fig. 7 a/). In other words, unlike the Gibe river, the peaks flow for the Awash river rises quickly to its peak and falls instantly. The peak flows of Great Gibe river at Abelti were flatter but sustained for approximately 7 to 8 days (Fig. 7 b/) due to the heavy rainfall intensities, during the first two weeks of August and longer durations, in addition to soil moisture when reaching saturation [40], [41] and [42].



a/ Rainfall and runoff plots for the Awash River at M. Hombole



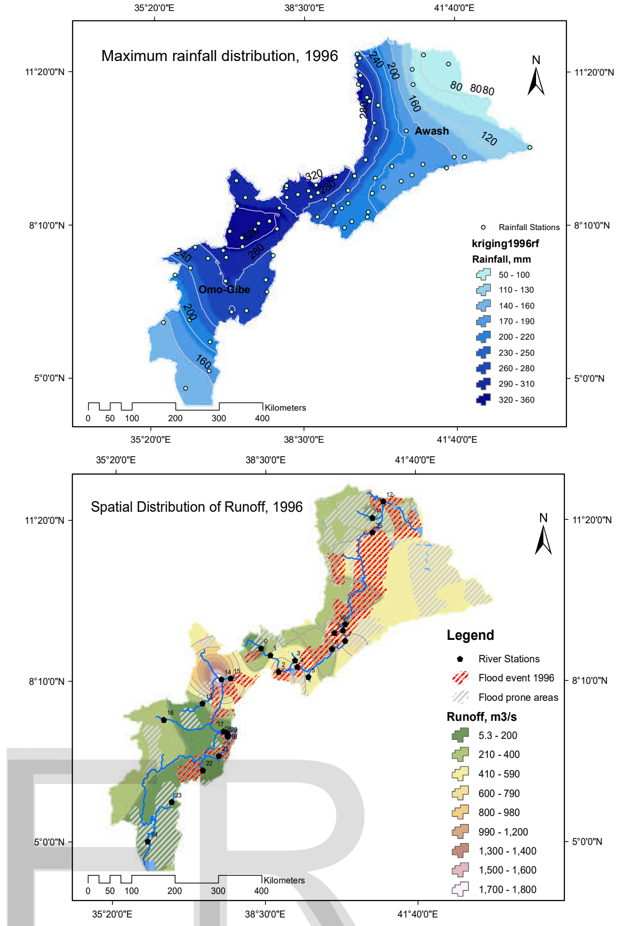
b/ Rainfall and runoff plots for the Great Gibe River at Abelti

Fig. 10. Correlation between rainfall and runoff in the Awash (a) and the Omo-Gibe (b) basins

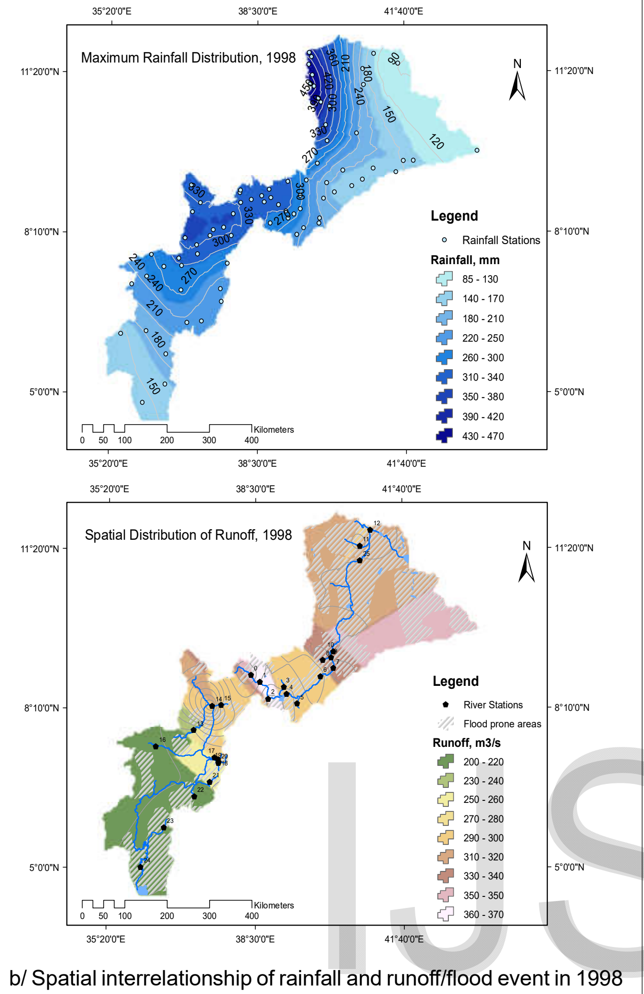
4.3.2 Spatial interrelationship

The spatial rainfall distributions and the extents of induced runoff from the rainfall for the prominent flood impacting years were identified and presented in Fig. 11. According to the results, the spatial distribution of both the rainfall and runoff for the identified flood years indicated that the uplands of the study basins receive more rainfall while the lowland areas received relatively lower rainfall. Based on the magnitudes of maximum rainfall events and the subsequent catchment responses to it resulted in peak runoff that triggers fluvial flooding.

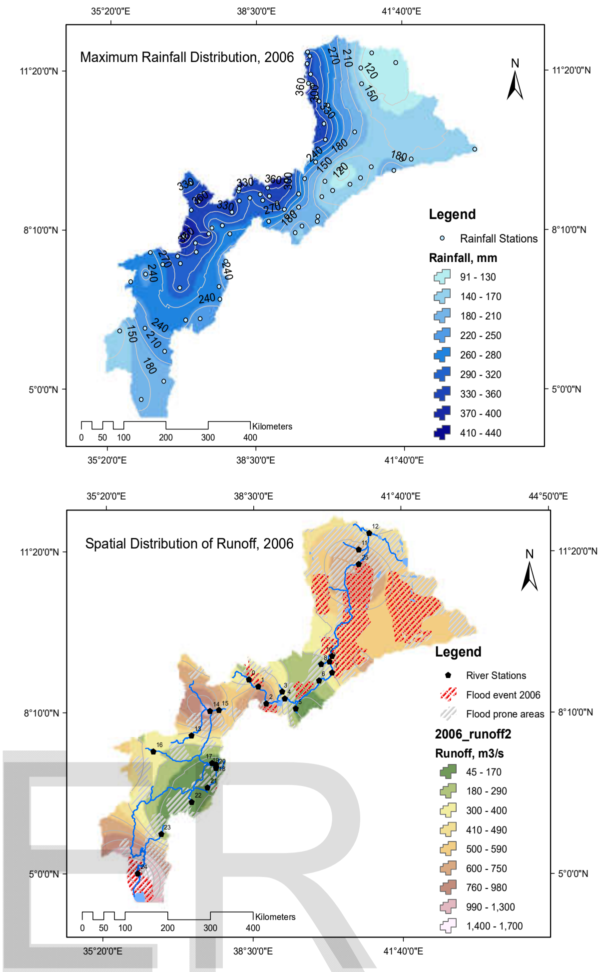
In addition, the temporal rainfall variability (Fig. 8**Error! Reference source not found.**, Fig. 9, and Fig. 10) and the spatial distribution (Fig. 11) of rainfall, runoff, and flood events were quite in agreement over the Awash and Omo-Gibe basins. The peak runoff at the identified gauging stations in both basins resulted from catchment responses due to high intensity and long duration of rainfall events triggered flooding and caused impacts over the flood vulnerable areas in 1996, 1998, 2006, and 2016 flood years.



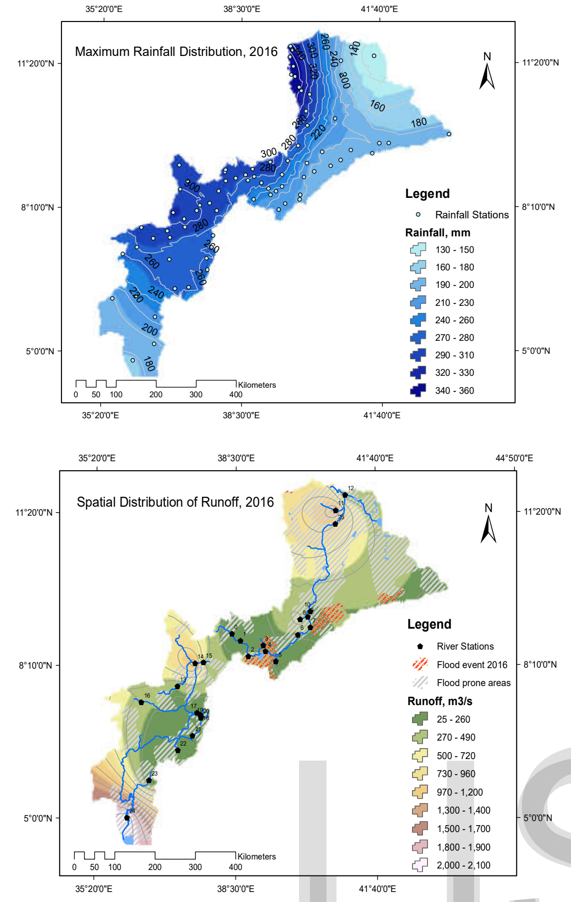
a/ Spatial interrelationship of rainfall and runoff or flood event in 1996



b/ Spatial interrelationship of rainfall and runoff/flood event in 1998



d/ Spatial interrelationship of rainfall and runoff/flood event in 2006



d/ Spatial interrelationship of rainfall and runoff/flood event in 2016

Fig. 11. Spatial distribution of rainfall (top) and runoff/ flood events (bottom)

4 CONCLUSIONS

The changes in precipitation, streamflow, and other hydrological variables in a changing climate/ weather shift and topographic nature can cause extreme events, such as floods or drought. Torrential precipitation, for instance, induced a likelihood peak runoff that triggers flooding over the flood-prone areas in Awash and Omo-Gibe river basins. This study was therefore mainly focused to analyze and evaluate the interrelationship of rainfall and runoff outcomes that triggers flooding in the two river basins. The statistical methods with GIS tools were adopted to assess the Spatio-temporal analysis and interrelation of rainfall, runoff and flood events. The in-situ of historical rainfall records, satellite-driven (CHIRPS) rainfall data and historical river flows with the knowledge of the study basins were the foundation of this study.

The rainfall distribution over the Awash and Omo-Gibe basins indicated an increasing and decreasing trend with variability in time and space. In this case, the Gurand-Meta, Haik, Combolcha, Asendabo, and Gibe-Farm weather stations showed statistically substantial increasing trends of rainfall in magnitude. In contrast, Akaki, Shola-Gebeya, and Wolkite weather stations showed a tendency of decreasing rainfall. Nonetheless, Addis Ababa, Ginchi, Metehara, Jima, and Welaita-Sodo weather stations did not show statistically significant changes. For instance, based on the slope of each weather station, Akaki showed decreasing trends with the slope value of -0.0058, and on the other hand, Gurand-Meta showed increasing trends with 0.0452 slope value. There was also a tendency of increasing trends in space when one moves from the north-eastern parts of the Awash Basin to the south-western and central highlands of the Omo-Gibe Basin. The mean annual rainfall estimated in the north-eastern part of the Awash Basin was 200mm, 1800mm at the central highlands, and 500mm in south-western lowland areas of the Omo-Gibe Basin.

The representing rainfall stations that induce peak runoff at the identified river gauging stations showed good correlations and triggers flooding. In the 2006 flood year (July to September), the peak streamflow of the Awash river at M. Hombole obtained was 1096.4m^3/s and the rainfall amount was 332.1mm which triggers flood. Based on the daily records between the 19th and 25th of August 1996 for instance, the peak runoff obtained on the 20th of August at M. Hombole river was 803.1m^3/s where the catchment responds to it with one day lag time of rainfall (156.2mm). The peak rainfall and peak runoff records were interrelated for 7 consecutive days (19-25 of August 1996) and obtained 0.9131 correlation value. Similarly, the daily peak rainfall and runoff relationship for the Great Gibe River gauging station at Abelti was robust and the runoff on August 20, 1996, obtained was 1810.7m3/s where the catchment responds to it with one day lag time peak rainfall of 180mm. The SPI index was also determined and confirmed that the likelihood of flooding events in the two study basins that range from rigorous floods (between 1.5 and 2) to the big floods (>2).

In summary, extreme climate and weather events that induce torrential rainfall with variability have modest to a significant contribution to runoff that triggers flooding. In this context, the flood events identified were 1996, 1998, 2006, and 2016 flood years that caused impacts in the flood-prone areas of the study basins. The interrelationships of rainfall, runoff and flood events are the findings of this study and will be used as a knowledge-base to understand the behavior floods in the study basins, and supports the flood management systems and decision-making facilities.

ACKNOWLEDGMENT

We acknowledge the National Meteorological Agency (NMA) and the Ministry of Water, Irrigation, and Energy (MOWIE) of Ethiopia for providing the climate and hydrological data for this study.

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