Precipitation and Temperature Trends over the Lake Tana Basin, Ethiopia

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Abstract

Analysis of precipitation and temperature extremes is important for water resource management, and ecosystem protection at various spatial and temporal scales. The main aim of this review paper critically evaluates and assess the existing data and field of research on trends and variabilities of precipitation and temperature extreme events. This study describes and formulates research findings on precipitation and temperature extremes variabilities, trends, and change point detections that occur within the study area considering the historical and future projected conditions. To realize a comprehensive assessment of a review, important research findings from research data support and academic research engines were used. The results revealed that the amount of precipitation did not show a consistent pattern within the Lake Tana basin under historical and projected timescales. The basin has more variation in monthly precipitation extremes, erratic and fragile than the seasonal and annual precipitation timescales. The minimum, maximum and mean temperatures have all increased significantly in most of the stations under RCP 2.6, RCP 4.5, and RCP 8.5 radiative forcing scenarios. All studies suggested that temperature change is more increasing pronounced than precipitation changes in the Lake Tana basin. The study provides useful information for comprehending precipitation and temperature extreme inconsistencies, tendencies, and characteristics within the Lake Tana basin.

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1. Introduction

The amount of precipitation and temperature changes are among the major climatic variables that are used to characterize extreme events, which can have profound effects on the spatial and temporal distribution of surface runoff, groundwater recharge, the occurrence of floods and droughts, and the ecosystem services (Andualem et al., 2020; Singh et al., 2021; Wazneh et al., 2020). Extreme climate events, when they occur, have substantial or devastating socio-economic, societal, and environmental impacts (Afuecheta & Omar, 2021; Guan et al., 2015; Malede, et al., 2022). Understanding the pattern of precipitation and temperature trends as well as their variability is important because most global challenges, such as food security, biodiversity loss, water security, and human health are linked to extreme occurrences caused by climate change (Afuecheta & Omar, 2021; Xu et al., 2017).

Global warming and climate variability are emerging as the most serious environmental issue of the twenty-first century, especially in developing countries. Ethiopia is one of the countries in the sub-Saharan region, and climate change has a significant impact on the country's economy (Birara et al., 2018; Malede, Agumassie, Kosgei, Andualem, et al., 2022). Many kinds of literature predict that increased temperature and changing precipitation intensity due to climate change will affect crop yields in many countries around the world, particularly in low-income countries with little adaptive ability for the change (Stige et al., 2006). Because agricultural production is the primary source of income in the majority of the rural population in developing countries, the adaptation of the agricultural sector to the diverse effects of climate change will be important in protecting the working poor livelihood and ensuring food security. However, many sub-Saharan African countries are becoming increasingly sensitive and less resilient to the effects of climate change. Extreme events such as droughts, floods, and wildfires are predicted to become more frequent, severe, and intense as the temperature rises (Pereira et al., 2021).

Observed changes in extreme events are associated with the intensity of the event, such as an increase in extreme temperature or an increase in the number of precipitation events in a particular location, although extreme events are a natural element of climate variability (Park et al., 2015). The precipitation and temperature extremes are predicted to be influenced by differences in variability since they are two components of the climate system. Research related to climate change and variability in the Lake Tana basin has yielded a significant number of studies (Abebe et al., 2017; Goshu & Aynalem, 2017). Rainfall is the major contributor to water resources in the Lake Tana basin and it is vulnerable to climate change and variability because of is highly influenced by geographic setting, diurnal wind directions, climatic features and it is one of the locations of extreme events, such as floods, droughts, and the heatwave of the lake are expected to increase in intensity and frequency (Buytaert et al., 2006; Kebede et al., 2006; Setegn et al., 2008).

The intention for this review arises from the need to reveal a thorough assessment of climate change and variability in high vulnerability areas of the Lake Tana basin, as well as to investigate the methods, and findings of precipitation and temperature change indicators used in such kinds of studies. Investigations that used observational evidence, statistical approaches, modeling experiments, as well as changes in projected scenarios were considered. This study investigates the recent state of research findings in the trends and variabilities of precipitation and temperature extremes over the highly sensitive Lake Tana basin, with the change of global warming in both historical decades and future projections circumstances. Investigating and identifying the possible changes in precipitation and temperature extreme indicators and vulnerability is important to strengthen the mitigation and adaptation measures, and serve as a platform for further research by presenting the status of the Lake Tana basin.

2. Study Area

The Lake Tana basin is found in the Ethiopian northwestern region and covers a total area of 15096 km^2, including the basins Lake area (Fig. 1). Geographically, the basin lies between the latitude of 10° 55'N and 12° 45'N and the longitude of 36° 40'E and 38° 20'E. Lake Tana is the largest lake in Ethiopia, the main source of water for the Blue Nile River, and it is a freshwater natural Lake that covers an area of 3000 – 3600 km^2 at an elevation of 1784 meters above sea level. The Lake has a maximum of 15 meters in-depth and it has approximately 84 km long, and 66 km wide (Setegn et al., 2009). The Gilgel Abay, Gumera, Rib, and Megech rivers are the major tributaries of the Lake Tana basin.

The estimated mean annual precipitation of the Lake Tana basin ranges from 1200 – 1600 mm, with a mean annual precipitation of around 1280 mm (Kim & Kaluarachchi, 2009; Setegn et al., 2009). Summer (Kiremet) is the basin's main rainy season, spanning from mid-June to mid – September, with the basin’s climate consisting mainly of tropical highland monsoon (Getachew et al., 2021). The air temperature shows strong diurnal but small annual and seasonal temperature variations, with a mean annual temperature of about 20 °C (Abebe et al., 2017). The basin had a unimodal rainfall distribution, and it received a high amount of rain during the main rainy season. For the availability of water resources, Lake Tana has a great economic value for the country, such as agriculture, water supply, and hydropower production. The basin has many economic potentials, such as Fogera, Dembia, and Gilgel Abay river mouth flood plain for irrigation potentials and Tiss Abay and Tana Beles hydroelectric power generation.

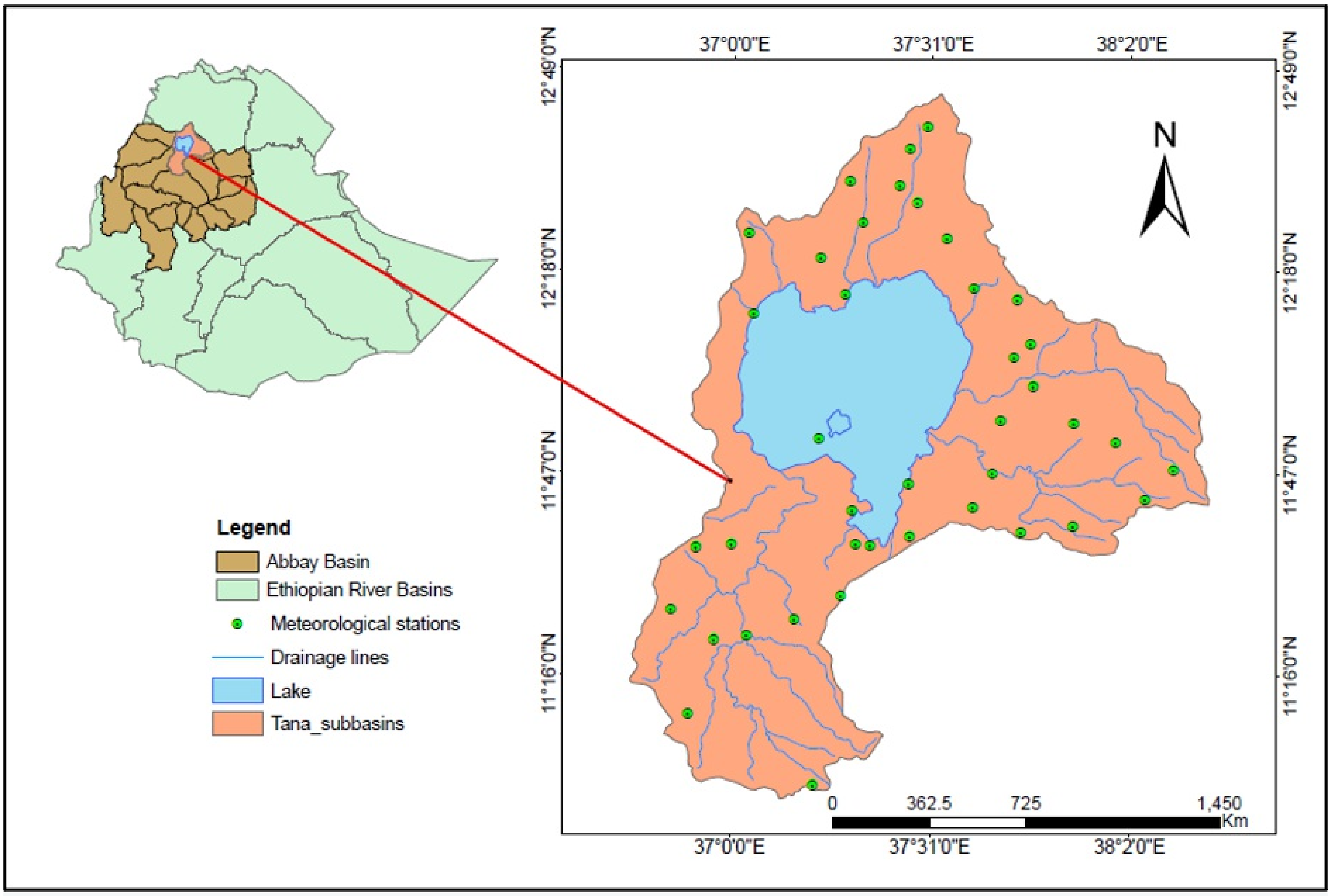

Figure 1. *Location map of the Lake Tana basin and the distribution of meteorological stations*

3. Methodology

To achieve a compressive assessment of the review, recent research findings from research data support and academic visibility engines were used. The data support and academic visibility engines were derived from the database of Web of Science, Scopus, and Google scholars. These data engines were important and provides useful information about the trends of precipitation and temperature variabilities that provided indexed and peer-reviewed research findings. A systematic review of studies on precipitation and temperature trends and variations was conducted (Petticrew & Roberts, 2008). The method was designed so that the authors were able to identify several evidence-based items for reporting a systematic review (Pereira et al., 2021). A systematic review can provide insight into trends and abstract relevant findings from a large amount of data (Özerol et al., 2018). The design of the method allowed the authors to identify several evidence-based items for reporting the review (Pereira et al., 2021). The review procedure included the following steps (Fig. 2), which are further described below.

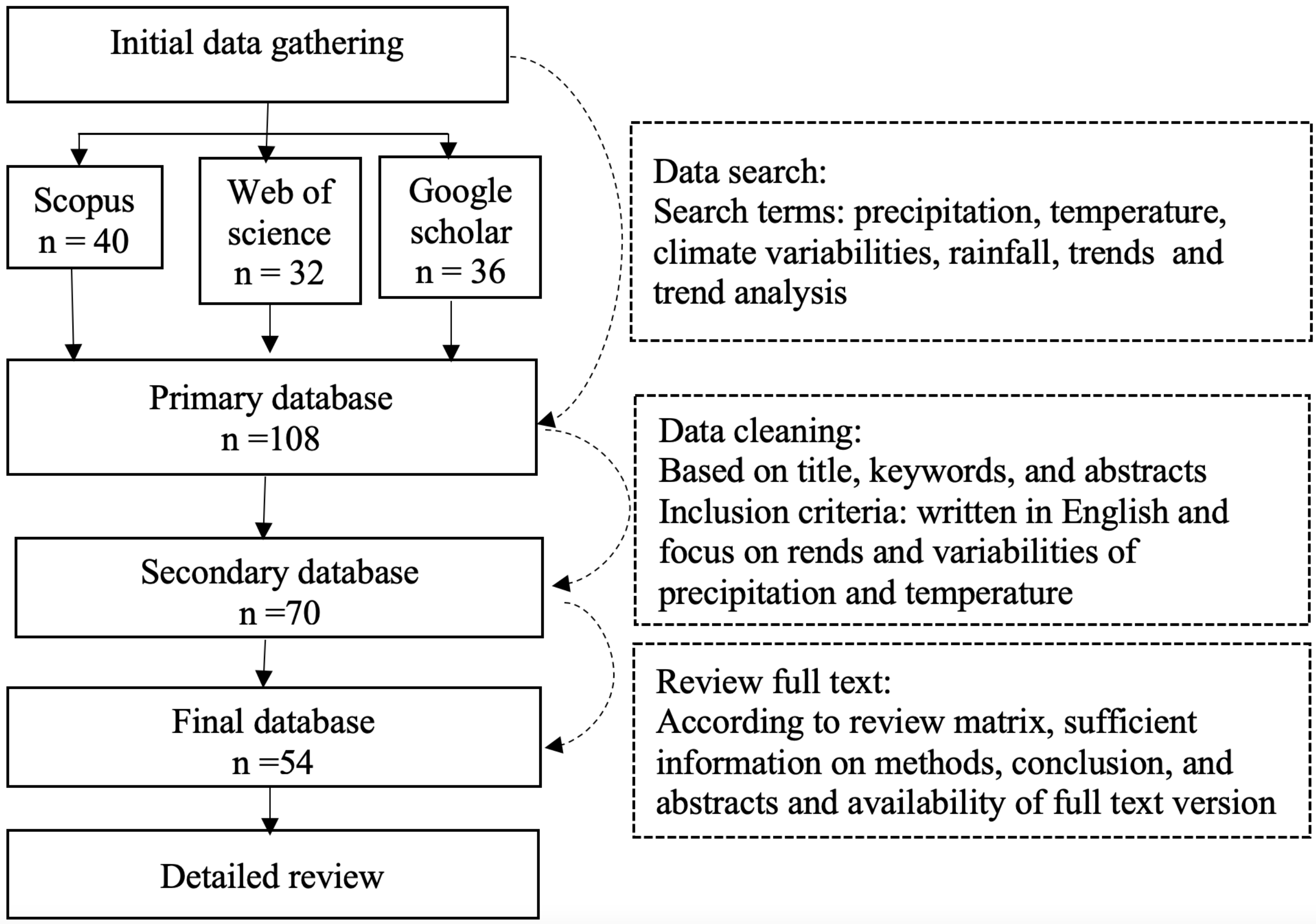

Figure 2. *A schematic representation of systematic review process*

The article, which included keywords such as trends, variabilities, precipitation, temperature, and trend analysis within the study basin, is considered the required information from the database engine. The most important articles were simply placed into the Mendeley folder collection database and used for further analysis after they were received from the search engines database, while the remaining articles were excluded from the analysis that has not much related and important for this study.

Web of Science, Scopus, and Google Scholar were employed and chosen for this study, because of their comprehensive coverage in the field of hydrology, perception, and temperature trends and variabilities. Many research and review articles were published under these data support and academic visibility search engine databases. During the data screening phase, duplicate and old forms of literature were removed from the investigation. The title, abstract, keywords, and full text of the published journal were used in the screening process. 60 publications were selected for inclusion in the final database from the 90 identified papers related to the trends and variabilities of precipitation and temperature extremes in the study area.

The final database included publications on the related keywords of precipitation and temperature extremes, trends, and variabilities, to advance a thorough understanding of the Tana Lake basin. The key inclusion criteria were implemented in the final review process by conducting an in-depth study of the whole text following the review matrix, as well as providing appropriate information on the abstracts, methodologies, data collection, and results from the analysis. A review matrix can assist to identify differences and similarities between journal articles on a specific research topic. The results presented here are based on an evaluation of the final 60 articles selected based on the geographic coverage of the matrix. A review matrix was guided by the final selection criteria, which confined entries to thematic and geographic scope, concepts of contemporary trends and variabilities of precipitation, and temperature extremes in the Lake Tana basin.

A detailed review process was used in addition to the initial search and screening. Inclusion criteria included enough information regarding the data sources, collections, methods, and analysis of hydroclimate variables. A review matrix included entries for thematic and geographical scope descriptions of hydroclimate, climate change, and data collection and analysis methods. Following the assessment of each publication's relevance, 54 final publications were reviewed.

Table 1. An overview of the search terms used and the number of publications that resulted

Search terms used in the database engine	Publication		
	Scopus	**Web of science**	**Google scholars**
“Hydroclimate” AND “climate change” AND “climate variabilities” AND “climate extremes” AND “precipitations” “temperature” OR “streamflow” OR “hydroclimate trends” OR “hydroclimate “variabilities”	40	32	36

4. Historical Precipitation and Temperature Extremes

Climate change is now increasing the occurrence, frequency, and magnitude of extremes, rising the risk of drought and flooding, particularly in developing countries like Ethiopia, where agricultural production is dependent on rainfall (Alemayehu & Bewket, 2016; Birara et al., 2018; Chen et al., 2014). Climate change, variability, and trend analysis of such as precipitation and temperature extremes at different timescale is important for water resource planning and management, agricultural planning, flood risk assessment, ecosystem management, and climate change adaptation (Alemayehu et al., 2020). Extreme precipitation events have played a significant influence in many national disasters and remain a persistent issue. It is a key contributor to significant socio-economic loss, including property destruction and loss of life (Davenport et al., 2021; Kunkel et al., 2020). When it happens, it has a devastating impact on society, the economy, and the environment (dos Santos & de Oliveira, 2017; Guan et al., 2015). The variability of surface air temperature extremes has received attention in recent decades, and it may have a significant impact on the global hydrologic cycle and energy balance through thermal forcing (Guan et al., 2015).

Birara et al. (2018) analyzed the trends and variability of rainfall and temperature in the Tana basin, using the Mann Kendall test and Sen’s slope estimators. The results indicated that the amount of annual rainfall was decreasing in the majority of the stations. For example, at Enjibara and Wegera the magnitudes have decreased by -5.92 and -9.74 mm/year, respectively. However, a positive trend with a magnitude of 1.18 mm/year was observed at the Addis Zemen stations. The minimum, maximum, and mean temperatures have all increased significantly at the majority of the stations. Similarly, Addisu et al. (2015) revealed that the mean, maximum, and minimum temperature had a generally increasing trend, whereas precipitation amount had a general decreasing pattern in the Lake Tana sub-basin. On the other hand, Weldegerima et al. (2018), on the other hand, examined rainfall trends over the Lake Tana basin from 1989 to 2015 using the Mann Kendall test and the Sens slope estimates. According to the findings, the quantity of annual rainfall in the Lake Tana basin is increasing, but at a statistically insignificant rate. The rainy rainfall (Kiremt) season accounts for 78% of total annual rainfall in the basin, while Bega and Belg provide 9.4% and 12.5%, respectively.

As described below most of the authors showed rainfall was a statistically nonsignificant trend. Fetene et al. (2018) showed that the highest precipitation for all stations occurred in July and August. Precipitation fluctuations are mostly governed by monthly, seasonal, and semiannual variations. Mengistu et al. (2014) reported that annual rainfall increased at statistically insignificant increasing trends by 35 mm per decade, whereas the maximum and minimum temperatures increased at a rate of 0.1 and 0.15 °C per decade throughout approximately 33% of the basin, respectively; however, the western part (12%) of the basin experienced declining trends on annual and seasonal timescales. Mohamed & Mahdy (2021) indicated that annual maximum and minim temperatures were increasing at a rate of 0.037 and 0.025 °C per decade respectively in the period from 1950 to 2018. Haile et al. (2009) showed the variability of rainfall over mountainous and adjacent Lake Tana areas using statistical methods. The results revealed that heavy rainfall events higher than 10 mm/hour were frequent at stations relatively closer to the Lake, whereas the lowest conditional mean rainfall of the hourly observations was observed over the mountainous area

Table 2. General overview of selected research findings on historical precipitation and temperature extremes in the Tana basin

Climatic variables	Data span	Used methods	Results	Authors
Annual rainfall and temperature	1980-2015	Mann Kendall Sen's slope	Rainfall decreasing and temperature increasing	Birara et al. (2018)
Annual rainfall and temperature	1940-2010	Mann Kendall trend test	Rainfall decreasing and temperature increasing	Addisu et al. (2015)
Hourly rainfall	(JJA), 2007	Statistical methods	Heavy rainfall near Lake and lower mountains	Haile et al. (2009)
Annual rainfall and temperature	1979-2015	Mann Kendall Sen's slope	Rainfall is not significant, temperature increasing	Weldegerima et al. (2018)
Seasonal and precipitation	1985-2015	Harmonic analysis	Precipitation increases in July and August season	Fetene et al. (2018)
precipitation and temperature	1986-2010	Statistical techniques	Increased temperature and no significant rainfall	Mengistu et al. (2014)
Monthly temperature variables Rainfall and temperature	1950-2018 1983-2016	Mann Kendall trend test Mann Kendall and Sen's slope	Increasing significantly	Mohamed & Mahdy (2021) Habte et al. (2021)

5. Projected Precipitation and Temperature Extremes

A number of climate extremes have recently been observed across the world. Continued emissions of greenhouse gases will cause long-term changes in the climate system, and increase the likelihood of widespread climatic extremes (Easterling et al., 2016; Giorgi et al., 2018). Getachew & Manjunatha (2021) indicated that maximum temperatures are expected to increase from 1.38 °C to 3.59 °C under RCP 4.5 scenarios by 2080s, while minimum temperatures are expected to increase up to 5.92 °C under RCP 8.5 by the end of the 21st century in Lake Tana basin. Annual precipitation projections, on the other hand, did not reveal a consistent trend over the basin. It increases by 255 mm in the northern and central parts of the basin and lowers by 200 mm in some parts of the basin. Similarly, Setegn et al. (2009) demonstrated that all projected temperature increases in the region for all periods and emission scenarios, while the projected precipitation showed an increase and decrease with the seasonal timescale. Tariku et al. (2021) also reported that the daily maximum and minimum temperature of the upper Blue Nile is projected to rise by around 1.35-2.38°C and 1.72-2.74°C under RCP 4.5 scenarios with the baseline period of 1976-2005. However, projected changes in mean annual precipitation vary greatly ranging from -10.3 to 19.4%. Dile et al. (2013) showed that annual mean precipitation over Gilgel Abay River in the Tana Lake basin may decrease in the first 30 years by -30% during (2010-2040), but increase by more than that during the next two 30 years (2070-2100).

Precipitation, on the other hand, does not show decreasing or increasing trend scenarios in the study area. According to Abdo et al. (2009), the finding of downscaled precipitation showed that, unlike minimum and maximum temperature, precipitation does not show a systematic increase and decrease reported that the findings of downscaled precipitation demonstrate that, unlike minimum and maximum temperature, precipitation does not show a systematic increase or decrease across all future time horizons for both A2 and B2 scenarios. according to Enyew et al. (2014), there was no trend in precipitation, but maximum temperature trends showed an upward trend at all stations, while minimum temperature trends showed a decrease in Gondar and Addis Zemen.

A consistent increase in both precipitation and temperature was also observed. Moges & Moges (2000) reported the characteristics of future extreme precipitation and temperature over the Tana Lake basin using the statistical downscaling model (SDSM) and projection of the regional climate model (REMO) for the baseline period. The results showed that both precipitation and temperature extreme events revealed a consistent anticipated increase in the Tana basin. Cherinet et al. (2019) indicated that annual precipitation increased slightly in most of the stations, whereas surprisingly, the average mean annual temperature trend increased dramatically. Desalegn et al. (2016) analyzed daily rainfall, and maximum and minimum temperatures for the forecasting period in the eastern Tana Lake basin, which ranged from 0 to 95.8 mm, 18 to 28 °C, and 9 to 18 °C, respectively. Worku (2015) observed similar rainfall trends when investigating the future climate change impact on rainfall variability using precipitation data from two global climate models (GCMs) output of HadCM3 and CGCM3. The findings indicated that precipitation extremes over the Blue Nile basin are likely to increase as a result of climate change.

Table 3. General overview of selected research findings on projected precipitation and temperature extremes in the Tana basin

Climatic variables	Data span	Used methods	Results	Authors
Precipitation and temperature	1986-2050	statistical downscaling	Both temperature and precipitation showed increase	Moges & Moges (2000)
Recitation and temperature	2080-2100	Hydrological modeling	Both showed increase trends	Setegn et al. (2009)
Precipitation and temperature	2011-2099	Hydrological modeling	Precipitation is not significant and temperature increasing	Abdo et al. (2009)
Daily Precipitation and temperature	2021-2100 2071-2100	Mann Kendall and Sen's slope	No trend precipitations upward for maximum temperature	Enyew et al. (2014)
Annual precipitation	2010-2100	SWAT model	Both decreased and increased tendency	Dile et al. (2013)
Annual precipitation and temperature	2050-2080	Hydrological models	Precipitation both increased and temperature increased	Tariku et al. (2021)
Perception and temperature	2011-2098	Hydrological model	Precipitation decreased and temperature increased	Ayalew et al. (2022)

6. Discussions

This review study provides a concise assessment of the most recent research findings on precipitation and temperature weather extremes in the Lake Tana basin by investigating the techniques and the conclusions using observational, statistical, and hydrological modeling studies with historical and future projections. Climate change has the potential to decrease the availability of water resources in Nile basin countries in the future decades, particularly anthropogenic climate change has the potential to alter the water balance in the Lake Tana basin (Setegn et al., 2011).

The historical temperature has shown an increasing trend in the Lake Tana basin. Mean, maximum, and minimum temperatures have increased almost in all stations. The maximum temperature at Bahir Dar, Dangila, Debre Tabor, and Gondar stations tend to increase by 0.04 °C, 0.05 °C, 0.06 °C, and 0.04 °C per year, while minim temperatures trend increase by 0.05 °C, 0.08 °C, 0.03 °C, and 0.03 °C per year, respectively (Getachew & Manjunatha, 2021). The change in temperature trends and variabilities are statistically significant in the majority of stations (Addisu et al., 2015; Birara et al., 2018; Dawit et al., 2019; Getachew & Manjunatha, 2021; Mohamed & Mahdy, 2021). For example, Birara et al. (2018) reported that temperatures in the Lake Tana basin have all increased during the previous 36 years (1980-2015). Getachew & Manjunatha (2021) also indicated that maximum temperatures increase from 1.38 °C to 3.59 °C under RCP 4.5 scenarios by the 2080s, while minimum temperatures increase up to 5.92 °C under RCP 8.5 by the end of the 21st century in the Lake Tana basin. These results agreed with research conducted in other parts of the world (Chattopadhyay & Edwards, 2016; Mahmood et al., 2019).

The projected temperature also has revealed an increasing pattern in the Lake Tana basin. Recent studies highlighted that the projection of extreme temperature showed an increasing trend rate in the Lake Tana basin for the near long-term periods (Alaminie et al., 2021; Ayalew et al., 2022). Similarly, Tariku et al. (2021) also reported daily maximum and minimum temperature of the upper Blue Nile is projected to rise by around 1.35-2.38°C and 1.72-2.74°C under RCP 4.5 scenarios with the baseline period of 1976-2005.

Unlike temperature, the trend and variability of precipitation have been inconsistent in the basin. Birara et al. (2018) and Addisu et al. (2015) analyzed the trends and variability of rainfall in the Tana Basin, using the Mann Kendall test and Sen's slope estimators. The results indicated that the precipitation amount had a general decreased trend in the majority of the stations. Incontrastly, Weldegerima et al. (2018), on the other hand, used the Mann Kendall test and the Sens slope estimates to examine rainfall trends over the Lake Tana basin from 1989 to 2015. The results showed that the quantity of annual rainfall in the Lake Tana basin is increasing but at a statistically insignificant rate. The rainy rainfall season accounts for 78% of total annual rainfall in the basin, while Bega and Belg provide 9.4% and 12.5%, respectively. Getachew & Manjunatha (2021) precipitation prediction did not show a consistent trend over the Lake Tana basin. Projected rainfall shows a decreasing trend at Dangila and Debre Tabor stations, whereas an increasing trend is noticed at Bahir Dar and Gondar stations.

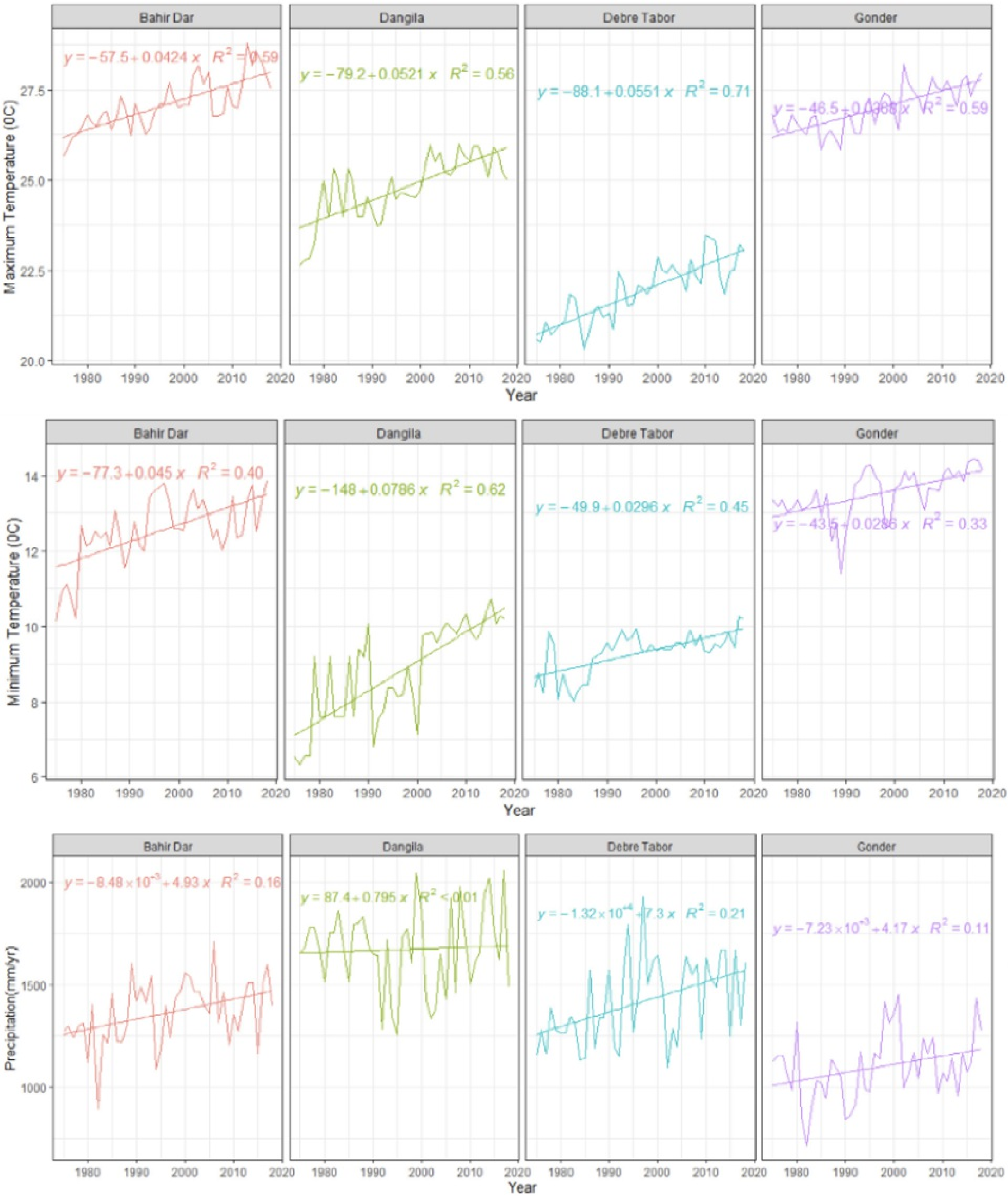

Figure 3. The mean annual trends of minimum, maximum, and precipitation at representative rainfall rain gauges of Bahir Dar, Dangila, Debre Tabor, and Gondar in the Lake Tana basin (Getachew & Manjunatha, 2021)

7. Conclusions

The trends of climatic weather variables, such as precipitation and temperature extremes as well as their fluctuation and inconsistency in the Lake Tana basin were assessed and examined for all research findings. Globally climatic weather extremes affect the importance of hydrological extremes for the requirement of human demands, such as drinking water supply, irrigation production, hydropower, and industrial activities in the spatial and temporal availabilities across the basin.

The Lake Tana basin is potentially rich in water resources and has been identified as a development corridor for the government and its communities. It contains many irrigation projects, rainfed agriculture, water supply projects, hydropower plants, and urbanizations which have been of very high economic importance to both the government and the livelihoods. As a result, the basin is suspectable and vulnerable to climatic variability and trends, which are becoming more severe as pressures on natural ecosystem services, water resource demands, and agricultural productions increase.

Precipitation in the Lake Tana basin did not indicate a noticeable trend both historically and in the projected. Maximum and minimum temperatures, on the other hand, are expected to increase in the Lake Tana basin by the 2020s, 2050s, and 2080s under RCP 2.6, RCP 4.5, and RCP 8.5 radiative forcing scenarios. All studies suggested that the temperature changes are more increasing pronounced than precipitation changes in the Lake Tana basin. To this effect, unstable climate change precipitation and temperature extremes have a significant impact on sensitive areas such as water resources, health, and agriculture. As a result, a basin-wide approach strategy, planning, and management are required to offset the present and future climate changes. Furthermore, future water resources and other development projects may need to account for climate extreme variability in their design and implementation.

Author contributions

Conceptualization, MDA and ATG; elaborated idea, MDA and ATG; methods, MDA; writing original draft preparation, MDA; formal review analysis, MDA and ATG; writing, review, and editing, MDA and ATG; visualization, MDA and ATG

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Conflict of interest

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