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Review Article

Climate Change and Water Resource Management in Ethiopia

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ABSTRACT

Climate change affects the hydrologic cycle, which changes the spatial and temporal availability of water resources. The primary goal of this paper is to examine the impact of climate change on the water resources in Ethiopia. Climate change will have a significant impact on water resources because water is essential to all natural ecosystems and humans. It affects the river basin's precipitation, temperature, and streamflow, endangering people's lives and livelihoods as well as life-supporting systems. Due to its location in the inter-tropical convergent zone, rainfall in Ethiopia river basin is highly erratic and seasonal. Temperature and sediment load are expected to rise in the future, while rainfall and streamflow are expected to decrease. Highly erosive rainfall, erodible soil, and shrinking forest cover characterize the Blue Nile basin. As a result, mitigation and adaptation strategies should be implemented.

Keywords: Climate change; Hydrological cycle; Water resource

INTRODUCTION

Climate change is one of the world's most pressing issues today. Changes in ordinary climatic conditions, as well as catastrophic events, are anticipated to have significant consequences for human and biological systems [1]. Understanding the effects of climate change and human activities on streamflow is critical for long-term water resource management in dry areas [2]. As the frequency of climatic extremes such as heat waves, droughts, and changes in rainfall patterns rises as a result of global warming, climate change will have a significant impact on the availability and unpredictability of fresh water [3]. Streamflow (SF), Surface Runoff (SR), Base-Flow (BF), and evapotranspiration are all affected by climate change (ET) [4]. Land-use change will have a higher effect on hydrologic responses than climate change. Stream flow increases would be exacerbated by the expansion of agriculture and the wetter environment, while irrigation and forest expansion would compensate [4]. Due to the effects of climate change and variability, hydrologic systems have been altering. Because of global warming, the effects of climate change are expected to worsen in the future. For integrated water resource management, quantifying the influence of climate change on spatial and temporal hydrological processes is critical [5]. Climate change is projected to have an impact on water availability through affecting hydrological variables like precipitation and temperature, which affect the hydrological cycle. Climate variability and change are directly linked to the intensity, timing, and frequency of e.g., runoff, floods, and droughts. With anticipated global warming, these effects would be particularly severe over countries, such as Ethiopia, that have already been influenced by climate variability in the past [6]. In most parts of the Basin, climate change projections showed an increase in mean annual temperature and a decrease in precipitation [6].

Precipitation is likely to vary greatly from one place to the next. Climate change (changes in the frequency and intensity of extreme weather events) is expected to have a significant impact on natural and human systems. Climate change, in terms of hydrology, can have a large impact on water resources due to changes in the hydrological cycle. Changes in temperature and precipitation, for example, can have a direct impact on evapotranspiration as well as the quality and amount of runoff components of the water balance. As a result, the spatial and temporal variability of water resources or the water balance in general, can be enormous, affecting agriculture, industry, and urban growth. Climate change is projected to have negative consequences for global socioeconomic development; the severity of the consequences will differ by country [7]. Recent hydrological study clearly demonstrated that probable climatic changes resulting by increased atmospheric trace gas concentrations will affect water quality by altering the timing and quantity of runoff and soil moisture, changing lake levels and groundwater availability [8]. In the mid-to long-term, climate change impacts on the water cycle could have a significant influence on regions that rely on groundwater to meet their water needs. Groundwater discharge regimes dominate the Lake Tana basin in Ethiopia [9]. Reduced precipitation would exacerbate the temperature-related effects (e.g., greater evapotranspiration, lower

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runoff) on the Colorado River's controlled water resources. The basin is especially vulnerable to reduced streamflow volumes due to the almost complete allocation of streamflow (on average) to consumptive uses, despite the system's high storage to runoff ratio, which may mitigate some of the effects of the timing shift associated with earlier runoff in a warmer climate (Figures 1 and 2) [3].

LITERATURE REVIEW

Climate change and ground water

The significance of the groundwater-climate change nexus cannot be overstated. The volume of groundwater in the world is believed to represent between 13% and 30% of the total volume of fresh water in the hydrosphere, and groundwater contributes 15% of the water utilized annually, with the rest coming from surface water. Droughts are alleviated by aquifers, which have a large storage capacity and are less susceptible to climate change than surface water bodies. Groundwater emptying from the store is, of course, the source of surface water base flow [10].

During the baseline period, groundwater accounts for more than half of each catchment's streamflow [11]. The contribution of groundwater to streamflow (GWQ) is reduced under RCP4.5. The reductions in GWQ range from 3 to 57 percent. Even for positive improvements in anticipated rainfall, same reductions are expected. For example, statistically significant decreases in GWQ (high confidence, p-values 140.001) are likely in the Gumara watershed for both time periods, although a minor rise in rainfall is expected. As a result of the increased rainfall intensities, the small increases in rainfall are projected to induce an increase in surface runoff and a decrease in infiltration. Although the effect of temperature on groundwater is difficult to measure, it can be deduced from other hydrologic components like AET (Actual Evapotranspiration) (Table 1).

The residual flux of water added to the saturated zone as a result of precipitation evaporative, transpirative, and runoff losses is known as groundwater recharge. It can happen through diffuse infiltration, which is a preferred pathway, as well as surface streams and lakes. As a result, climatic factors, local geology, topography, and land use all play a role in groundwater recharge. In general, measured groundwater recharge is a site-specific quantity, which makes determining its regional impact more difficult. The broad scenarios provided by GCMs should only be used as a starting point for further research into the effects of climate change on groundwater. Any study of recharge variation must be based on data and investigations specific to the hydrogeological system in question [10]. The impact of climate change on groundwater recharge is difficult to predict. Changes in precipitation intensity will affect the amount of total runoff that recharges groundwater. In humid areas, increased precipitation intensity may decrease groundwater recharge because the infiltration capacity of the soil will be insufficient. In semi-arid areas, increased precipitation intensity may increase groundwater recharge due to the faster rate of percolation through the root zone, which will reduce evapotranspiration (Table 2 and Figures 3 and 4) [6].

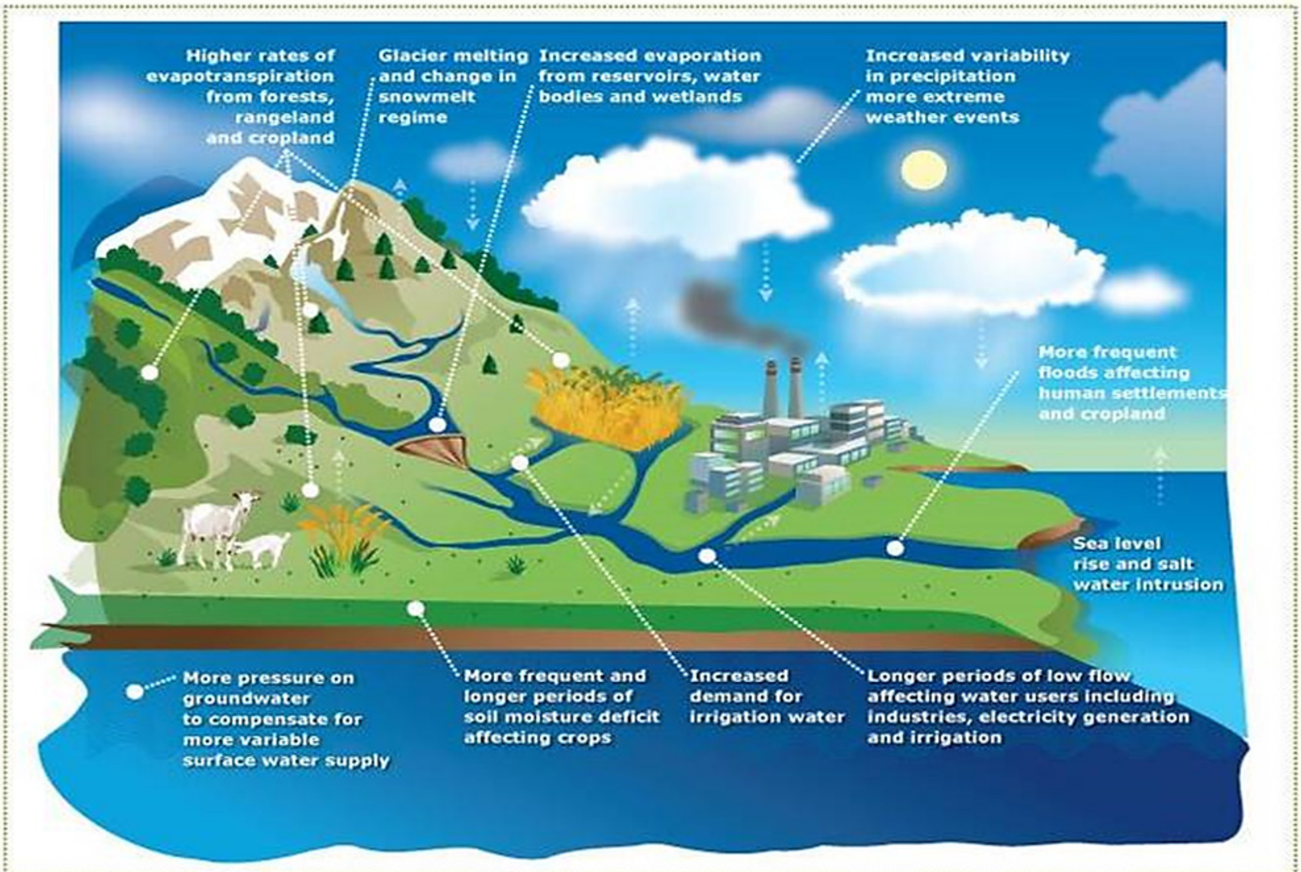

Figure 1: How climate change affects all the elements of the water cycle and its impact on agriculture.

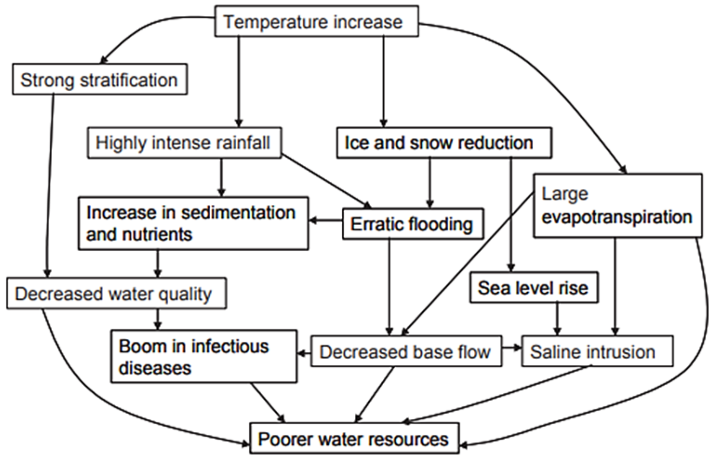

Figure 2: Influence temperature increase to water resource.

Table 1: Correlation matrix of annual hydrological variables computed using Pearson correlation method for the time series (2031–2100) for Gilgelabay and Gumara catchments (numbers in bold color show either strong positive or negative correlation).

Catchments	Rainfall	ET	SURQ	GWQ	WYLD	Mean temperature
Gilgelabay						
Rainfall	1	0.64	0.69	0.94	0.94	-0.12
ET	0.64	1	0.1	0.44	0.38	0.01
SURQ	0.69	0.1	1	0.64	0.8	0.2
GWQ	0.94	0.44	0.64	1	0.97	-0.27
WYLD	0.94	0.38	0.8	0.97	1	-0.15
Mean temperature	-0.12	0.01	0.2	-27	-0.15	1
Gumara						
Rainfall	1	0.23	0.8	0.75	0.98	-0.17
ET	0.23	1	0.06	0.04	0.07	-0.15
SURQ	0.8	0.06	1	0.26	0.81	0.26
GWQ	0.75	0.04	0.26	1	0.77	-0.53
WYLD	0.98	0.07	0.81	0.77	1	-16
Mean temperature	-0.17	-0.15	0.26	-0.53	-0.16	1

Table 2: Impacts of climate change and non-climatic drivers of change on water resources for agriculture.

Types of hydrological change	Impacts from	
	Non-climatic drivers	Climate changes
Change in annual precipitation	No or minor impact	Expected to increase globally during the 21st century, with potentially significant spatial variations
Interannual precipitation variability	No impact	Expected to increase everywhere
Agricultural droughts	Limited impact: Some agricultural practices can deplete soil moisture faster than natural vegetation	Moisture stress to generally increase as a result of increasing variability of rainfall distribution (i.e. longer periods without rain) and increasing temperatures.
Exposure to floods	Moderate impact: Flood intensity and impact can be exacerbated by changes in land use and unplanned development in alluvial plains	Percentage of global population annually exposed expected to increase.
Snow and glacier melt	Limited impact through deposit of pollutants and change in the reflecting power of the surface (albedo)	Rising temperatures lead to accelerated snow and glacier melt with initial increases in river flow followed by decreases.
Change in river discharge	High impact in water scarce areas, where reservoir construction and water diversion for agriculture and other uses are modifying runoff regimes and reducing annual flow. Large-scale water conservation measures also have an impact on river discharge	Increased variability as a result of changes in rainfall patterns. Changes in snow and glacier melt induce changes in seasonal patterns of runoff. Changes in annual runoff expected to vary from region to region.

Change in groundwater resources	High impact: Large-scale developments of infrastructure to withdraw groundwater resources in many regions are already threatening the sustainability of aquifers in many dry areas.	Varies as a function of changes in rainfall volumes and distribution.
Increase evapotranspiration	Limited impact in agriculture: some crops have higher evapotranspiration rates than natural systems, other less	Increases as temperatures rise
Water quality (in rivers, lakes and aquifers)	High impact from pollution in highly developed areas	Moderate impact due to increased temperatures
Salinity in rivers and aquifers	High impact from water withdrawal in highly developed areas, mostly in arid regions.	Potentially high impact where sea water level rise combines with reduced runoff and increased withdrawal

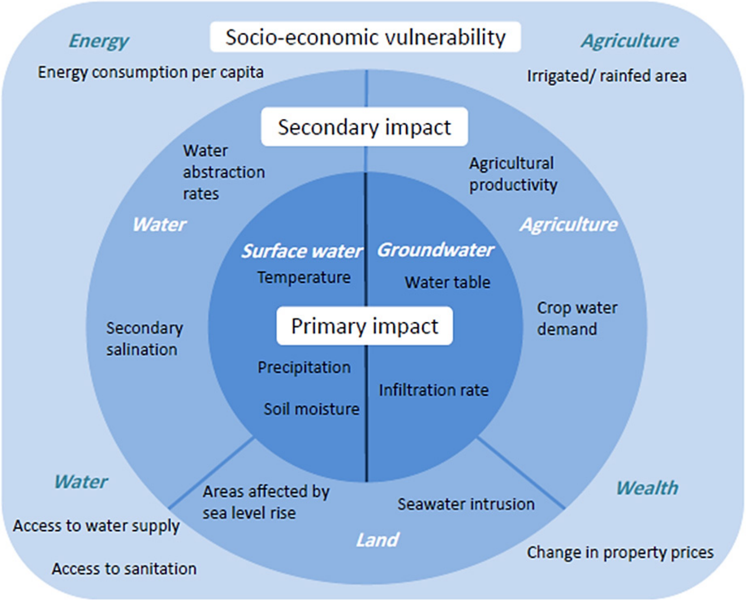

Figure 3: Impacts of climate change water resource.

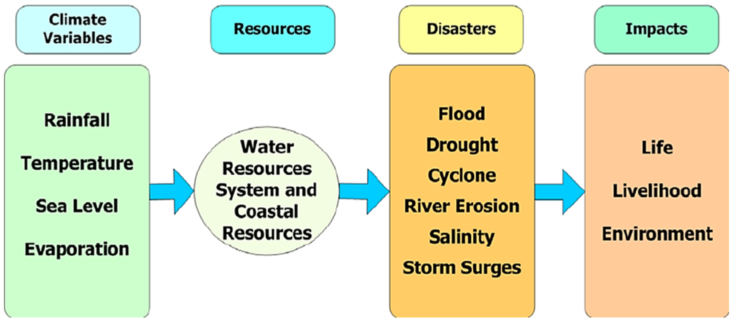

Figure 4: Impacts of climate change on water resource.

Climate change and water balance

Climate change impacts on the water cycle can severely affect regions that rely on groundwater to meet their water demands in the mid- to long-term. In the Lake Tana basin, Ethiopia, discharge regimes are dominated by groundwater. We assess the impacts of climate change on the groundwater contribution to streamflow (GWQ) and other major water balance components in two tributary catchments of Lake Tana [9].

Under both RCP4.5 and RCP85, water yield in the Gumara basin is predicted to increase in the mid-century. In the long run, however, a decline in RCP4.5 and an increase in RCP8.5 are projected. The direction of these shifts corresponds to the direction of rainfall fluctuations. Variations in the water balance components can be exacerbated by even minor changes in rainfall amounts. This has something to do with a rise in rainfall intensity. Rainfall will be more varied and intense than during the baseline period, according to the ensemble average.

During the baseline period, groundwater accounts for more than half of each catchment's streamflow [11]. The contribution of groundwater to streamflow (GWQ) is reduced under RCP4.5. The reductions in GWQ range from 3 to 57 percent. Even for positive changes in projected rainfall, these reductions are expected. For example, statistically significant decreases in GWQ (high confidence, p-values 140.001) are likely in the Gumara catchment for both time periods, while a slight increase in rainfall is expected. As a result of the higher rainfall intensities, the slight increases in rainfall are expected to cause an increase in surface runoff and a decrease in infiltration. Although the effect of temperature on groundwater is difficult to measure, it can be inferred from other hydrologic components like AET (Figure 5) [9].

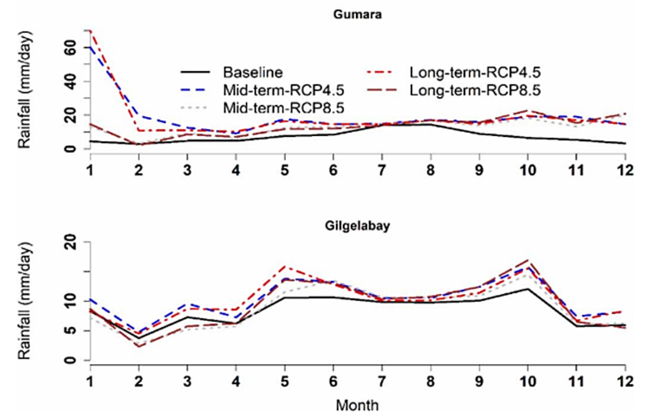

Figure 5: Expected average monthly rainfall intensity (mm/day) of mid- and long-term periods as compared to the baseline period (1985–2014).

Flooding and drought

Drought and flooding are two natural hazards that are becoming more common in various climate zones around the world. Extreme floods are becoming more common each year as a result of climate change, causing human suffering and significant economic damage in various parts of the world. Flooding and drought are two of the most common natural occurrences in the Blue Nile River basin, resulting in food insecurity and other complex social issues. In northern Ethiopia, severe drought occurs every ten years. Water quality and quantity are further harmed by high temperatures, floods, and droughts. Droughts will become more common as a result of climate change. A variety of non-climatic and climatic factors influence flooding processes. Soil type, slope, and antecedent soil moisture are examples of non-climatic factors [12].

Climate change and sediment yield

Sediment delivery and transport in Mountain Rivers has an impact on aquatic habitat and water resource infrastructure. Although significant changes in hydrology and stream temperature are expected as a result of climate change, the effects of climate change on sediment yield have received less attention. The effects of temperature and hydrology on vegetation disturbances are expected to increase sediment yield as a result of climate change (wildfire, insects, and drought-related mortality). Desertification, drought, coastal flooding, and other extreme weather events are all potential effects of climate change in developing countries. Climate change has an impact on water budget components and climatic variables, which has a negative impact on water body sedimentation. It causes extreme precipitation and high sediment yield. Furthermore, climate change hastens soil erosion by amplifying the erosive power of wind and rainfall. This, in turn, causes a sedimentation issue in a waterbody.

Climate change and stream flow

The contribution of baseflow to the total water yield of the Basin is expected to fall to 11.4 percent by the end of the twenty-first century, down from 41.3 percent during the baseline period. The decline in the Basin's total water yield is partly explained by the decrease in base flow. Changes in the hydrologic balance will have a significant impact on the Basin's water management [6]. The potential evaporation of soil water is calculated as a function of PET and leaf area index (area of plant leaves relative to the soil surface area).

An exponential function of soil depth and water content is used to estimate actual soil water evaporation. Plant water evaporation is modeled as a linear function of PET, leaf area index, and root depth, with soil water content acting as a limit. To support soil water processes such as infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers, the soil layer is subdivided into multiple layers. When the field capacity of a soil layer is exceeded and the layer below is not saturated, downward flow occurs. The shallow aquifer is recharged by percolation from the bottom of the soil profile. Percolation and lateral subsurface flow in the soil profile are calculated at the same time. The contribution of groundwater flow to total streamflow is simulated by routing shallow aquifer storage. As a result, potential evapotranspiration is expected to rise by 7.8%, despite the fact that annual rainfall trends do not show statistically significant differences between years. The rainfall pattern has been found to have significant seasonality, with dry season rainfall amounts likely to increase and wet season rainfall amounts likely to decrease. Climate change will have a significant impact on the local hydrology of the study watersheds, according to the hydrological model. Overall, streamflow in both rivers will increase by up to 64% in dry seasons and decrease by 19% in wet seasons by the end of the century [3]. Annual yield, summer low flows (average, extreme), peak flows (scouring floods), peak flow seasonality, and center of runoff timing are all important streamflow changes for aquatic species, water supply, and infrastructure. During the summer, irrigation water for crops and urban landscapes is typically required. Annual yield, summer low flows, and center of runoff timing are important water supply metrics, but they are more relevant to surface water supplies than groundwater supplies, despite the fact that changes in long-term annual means could be useful for the latter. Summer low flows are calculated using the mean summer yield (June through September). The date on which 50% of the annual runoff has flowed out of a basin is known as the center of runoff timing, and it is an effective index for the timing of water availability in snowmelt-driven basins. Streamflow timing is disconnected from water supply when the runoff is earlier in the winter or spring (Figure 6).

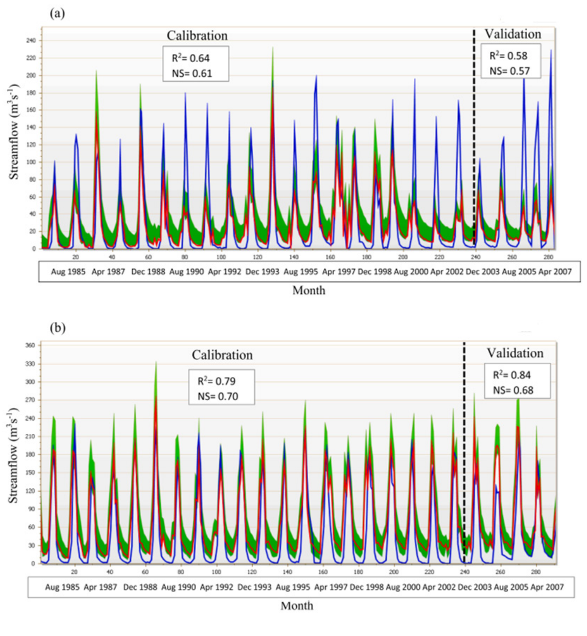

Figure 6: Climate change impact of stream flow Blue Nile River Basin. **Note:** (⋀) Observed, (⋀) Best estimation, (▲) 95PPU.

DISCUSSION

Temperature, streamflow, precipitation trends

The study of temperature, precipitation, and streamflow availability trends is generally regarded as a statistical approach to detecting non-stationarity in time arrangement [13]. In the Blue Nile river basin, numerous studies on streamflow, temperature, and precipitation trends have been conducted [13,14]. Gebrehiwot et al. [15], Gebremicael et al. [14], Rientjes et al. [16], Legesse et al. [17], and others, for example, investigated and analyzed the long-term trend of streamflow in the Blue Nile River basin. Despite this, the conclusions of those studies were not in agreement. According to Gebremicael et al. [14], Legesse et al. [17], and Rientjes et al. [16], the annual flow in the Blue Nile River is increasing, whereas Gebrehiwot et al. [15], the annual and seasonal flow in the basin is decreasing. It's understandable that the majority of these studies concentrated on total streamflow and precipitation on an annual and seasonal basis, with little attention paid to extreme conditions like extreme heat. As a result, this paper tries to fill in the gaps left by other studies (Table 3).

Table 3: Surveyed studies on historical trends in the hydrological process are summarized in this report.

Location	Variable	Result	Authors	Time
Nile basin	Annual rainfall	No long-term trend Ethopian highlands	Taye et al. [13]	1900-1998
Northern Ethiopia	Total precipitation	No trend in total precipitation	Seleshi et al. [19]	1965-2002
UBNB	Annual and monthly precipitation	No significant trends	Tekleab et al. [18]	1970-2010
Tana Lake	Total seasonal and annual precipitation	No statistically increasing trend	Mengistu et al. [6]	1981-2010
	Annual and seasonal temperature	Significant increased trend		
Gilgel Abay	Average monthly and annual precipitation	There was no significant trend	Tekleab et al. [18]	1970-2010
UBNB	Annual and seasonal rainfall and runoff	No significant change in rainfall. A significant increase in runoff during the rainy season	Tesemma et al. [20]	1964-2003
Gilgel Abay	Low and high streamflows	Increased in low and high streamflow index	Rientjes et al. [16]	1973-2001
Lake Tana	Mean seasonal streamflow sediment load	Significant increase (26%) increasing trend	Gebremicael et al. [14]	1970-2009

Gebremicael et al. [14] investigated the Blue Nile river basin's total annual precipitation trend from 1970 to 2009. Eight out of nine stations in the Upper Blue Nile basin have little change in average annual rainfall, according to this study. Only one of the nine stations showed that annual precipitation had changed significantly. Between 1970 and 2010, Tekleab et al. [18], looked at total monthly and annual scale precipitation in the Kiremt (rainy) season. The average annual and seasonal precipitation over 13 stations within the basin showed no statistically significant trends, whereas the mean annual temperature over the basin varies by 10 degrees Celsius over Ethiopia. Over the period 1965–2002, Seleshi et al. [19] examined changes in annual rainfall at 11 stations in various Ethiopian climatic regions. For trend analysis, they used the progressive Mann– Kendall trend test. The result showed that there was no total seasonal and annual rainfall change trend over northwestern, northern, and central Ethiopia. Tesemma et al. [20] also investigated the trend of average monthly runoff and rainfall of the Blue Nile river basin over the period 1964–2003. The study's findings revealed that there was no statistically significant change trend in the basin's annual and seasonal precipitation. During the rainy season (June–September), however, there was a significant increase in runoff. From 1981 to 2010, Mengistu et al. [6] investigated the temporal and spatial variability and trend of seasonal and annual temperature and rainfall in Ethiopia's Blue Nile basin. The least squares method was used to evaluate the trends using the slope of the regression line. The statistical significance of the trend was determined using the F-distribution in this study. The annual minimum and maximum temperatures of the basin were found to be increasing at a significantly higher rate (33 percent), but the minimum temperature was increasing at a faster rate than the maximum temperature. Except for the spring season, there was no discernible upward trend in seasonal and annual rainfall. In the spring season, rainfall in the basin showed a not-so-significant decline (11 percent).

CONCLUSION

Climate change is becoming a hot issue in the global environment, according to this review, because it affects water resources that humans rely on for drinking, crop production, and manufacturing. Climate change has a wide range of effects on water resources. It affects the availability of water in terms of both space and time. It results in excess water in some areas while causing drought in others. Climate change raises demand for water while reducing supply (availability). The majority of the river basin is one of the most severely impacted by climate change rivers. Highly erodible soil, dissected and steep terrain, and fragmented land use dominated by smallholder livestock and crop production characterize the basin. High soil erosion, soil fertility loss, lower water holding capacity, and, in general, land degradation and poverty are caused by the basin's landscape and land use characteristics combined with the erosive nature of the rainfall.

Climate change affects water resources in many ways. It alters the spatial and temporal availability of water. It causes too much water in some areas while there is a drought in some other regions. Climate change increases the demand for water while diminishing the supply (availability). Climate change affects the water resources of the Blue Nile basin in many ways. The sediment yield in the basin is high and will increase by 21.3% in the 2080s due to high erosion. Evapotranspiration in the basin is also increasing by 19%, while rainfall is reducing by up to 25%.

As a result, mitigation and adaptation strategies should be implemented while taking into account all of the basin's characteristics and issues. This basin can benefit from both proactive and reactive adaptation strategies. Watershed management, such as agroforestry, afforestation, soil water conservation, and stream bank rehabilitation, is the best strategy. This strategy can reduce carbon dioxide emissions as well as mitigate the effects of climate change.

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