THE VOLTA LAKE AND DECLINING RAINFALL AND STREAMFLOWS IN THE VOLTA RIVER BASIN

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Abstract. This paper looks at the rainfall and streamflow patterns over two distinct time periods, i.e., 1950–1970 and 1971–1991 within the two most prominent catchments in the Volta river system – White Volta and the Oti basins. The first period (1950–1970) represents relatively vegetated catchments and low population whilst the latter (1971–1990) represents intense land use practices resulting from increased population that have severely degraded the environment. These two catchments are among the most significant contributors to the Volta lake. The Volta lake, which was formed between 1962 and 1966 in Ghana and created primarily for hydroelectric power generation, will probably be one of the greatest man-made lakes for a long time. It produces 912 MW of electricity at its maximum operating capacity. Recently, there have been declines in the lake levels resulting most probably from inadequate rainfall and/or runoff from the river catchments that feed the lake. Comparisons of runoffs for the two time periods show reductions in mean streamflows of 32.5% at Saboba on the Oti and 23.1% at Nawuni on the White Volta.

Key words: hydroelectric power generation, reductions in rainfall, reductions in streamflows, rise in temperature within basin, Volta lake.

1. Introduction

There are two hydroelectric power (HEP) projects on the Volta river at Akosombo and at Akuse, a much smaller Kpong project 21 km downstream of Akosombo. These two HEP projects have a current generating capacity of 1072 MW or 92% of the total installed electricity generating capacity of 1160 MW. The two HEP projects are fed by the Volta river system, prominent among which are the White Volta and the Oti river catchments. Since the early 80s, the lake levels have seen periodic declines resulting in the hydroelectric projects not being able to generate the required electricity to satisfy both domestic and industrial consumptions. This situation at times calls for power rationing as happened in 1983 and recently in 1998. The resulting economic implications are enormous.

Since about 1970, there has been increased human activities resulting in poor agricultural practices (i.e. shifting cultivation), surface mining, use of fire for illegal hunting and its attendant bush fires, cutting of trees for fuel wood and charcoal production, etc., which have severely degraded the environment. It is therefore necessary to study the rainfall and streamflow patterns in the Volta basin in response to the population expansion and the changing land use practices in order to provide a database for the operation of the Volta Lake.

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2. The study area

2.1. THE WHITE VOLTA BASIN

The White Volta together with the Oti river basins form the study area as shown in Figure 1. The White Volta basin has an area of 106,742 km^2 and lies partly in Ghana, Burkina Faso and Mali. The portion in Ghana is often referred to as the lower White Volta basin and it is this part which is considered mostly in this work. The lower White Volta basin which occupies an area of about 49,226 km^2 lies between latitudes $8^\circ 30'$ and $11^\circ 0'$ N and longitudes $0^\circ 0'$ and $2^\circ 30'$ W. It covers the entire upper east region and significant portions of the upper west and northern regions. However, the total area of the entire catchment upstream of Nawuni, a discharge measuring station, is about 96,957 km^2.

The geology is dominated broadly by the Voltaian formation, and the Birimian and its associated granite rock formations. The Voltaian formation consists mainly of sandstone, shale, arkose, mudstone, sandy and pebbly beds and limestone. The Birimian is part of the basement complex consisting mainly of gneiss, phyllites, schists, migmatites, granite-gneiss and quartzites. Generally, the basin is characterized by wide and almost flat plains in its lower parts and by undulating hills at elevations of between 60 and 80 m in its upper section.

The climate of the basin is dominated by two distinct seasons. The dry season begins in November and ends in April while the wet season is between May and October with a peak in September. Mean annual rainfall ranges from 1015 mm in the north to about 1140 mm in the south. The mean annual rate of pan evaporation is about 2540 mm (Nathan Consortium, 1970). The average air temperature is approximately 27.8 °C and the mean relative humidity rises up to about 80% in September and lowers to about 20% in January.

This basin lies entirely within the interior wooded savannah ecological zone, dominated by grasses and trees such as baobab, dawadawa, neem and sheanut. The prevailing soils according to the Ghana classification system based on the Charter's Interim Scheme (Brammer, 1956) are savannah ochrosols, groundwater laterite and groundwater laterite-ochrosols and acid gleisols.

2.2. THE OTI BASIN

The Oti basin is shared between Ghana, Burkina Faso, Togo and Benin. It occupies an area of about 75,110 km^2 out of which only 16,801 km^2 lies in Ghana. Saboba, with a catchment area of about 54,890 km^2, is the main discharge measuring station on the Oti river. The Oti basin though only about 18% of the total catchment contributes between 30% and 40% of the annual flow of the Volta (Moxon, 1968). The reason for this is that the catchment of this river is the most hilly and mountainous in the whole Volta basin.

The northern part of the Oti basin receives an annual rainfall of about 1015 mm while the south experiences about 1397 mm of rainfall on the average per year as compared to pan evaporation of 2540 mm per annum (Nathan Consortium, 1970). The basin is underlain mainly by the Voltaian and Buem formations. The Buem formation is composed basically

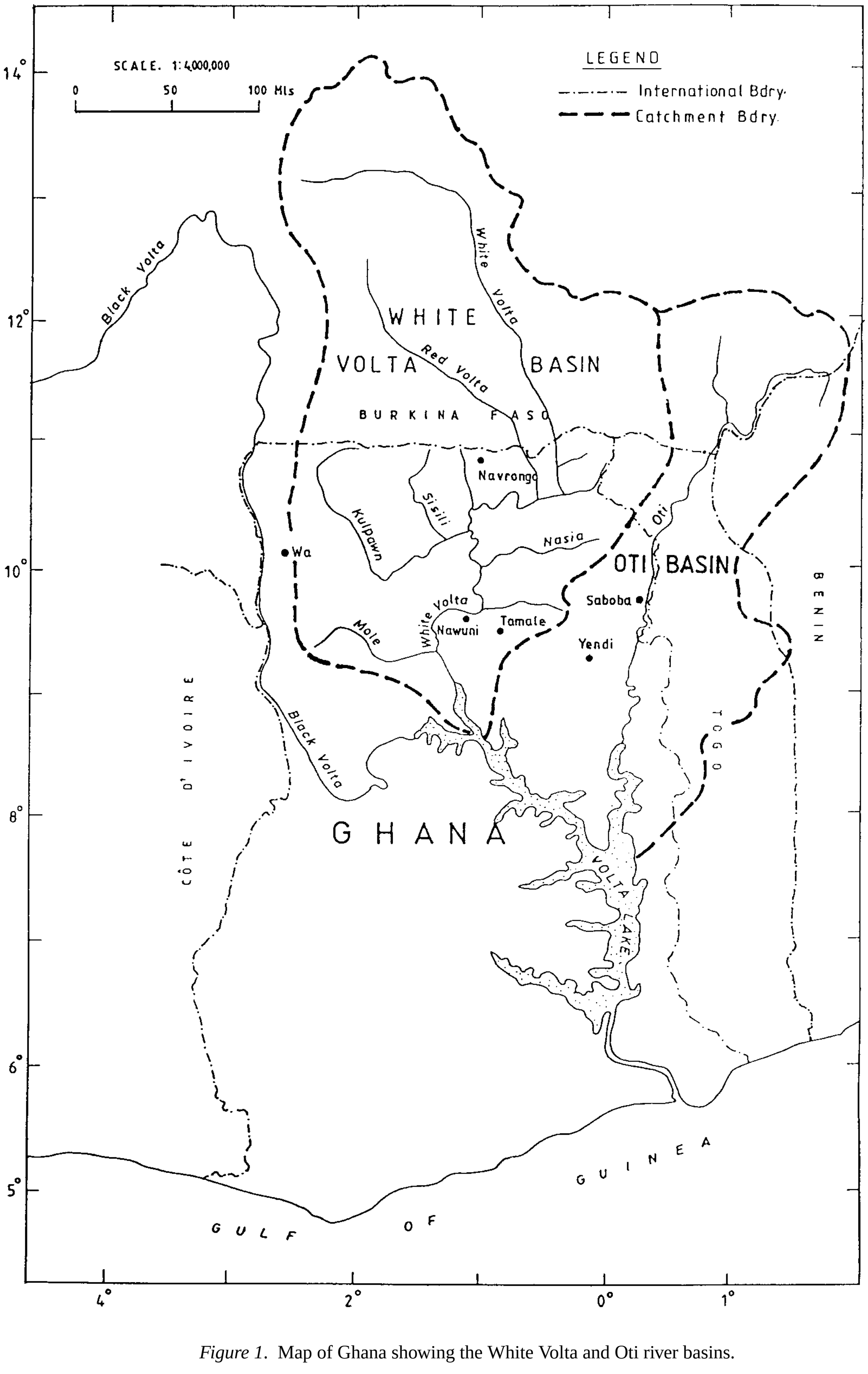

Figure 1. Map of Ghana showing the White Volta and Oti river basins.

of sandstone, shale, limestone and quartzites. Over 3,000 boreholes have been drilled in the White Volta and Oti basins.

The principal soils are the savannah ochrosols whilst the vegetation is generally made up of dense grasslands with medium broad-leaved trees which thins out northwards.

3. Materials and methods

Two data sets of daily discharges and four monthly rainfall totals were obtained for this study. The daily discharges were available from 1955 to 1990 for Nawuni in the White Volta basin and from 1953 to 1990 for Saboba in the Oti basin. Monthly rainfall totals and mean monthly air temperatures from 1950 to 1991 were obtained for the synoptic stations of Tamale, Yendi, Wa and Navrongo. Tamale, Wa and Navrongo synoptic stations represent the White Volta basin while Yendi is taken as representative of the Oti basin. The discharge data were supplied by the Hydro Division of the Ministry of Works and Housing whereas the rainfall and temperature data were obtained from the Meteorological Services Department of Ghana, Accra.

On the basis of population expansion and changing land use practices which intensified after 1970, the data was divided into two periods, i.e., 1950–1970 and 1971–1990 to reflect the two distinct periods. This is supported by studies in West Africa which revealed a clear rainfall deficit trend since the 1970s in both the forest and savannah zones (Aka et al., 1996; Paturel et al., 1997; Opoku-Ankomah and Amisigo, 1998). The first period (1950–1970) represents low environmental degradation while the second represents high population and severe environmental degradation in the catchment.

The analyses were carried out on annual basis and the annual discharges were obtained as averages of monthly discharges for each calendar year. The discharges for the two time periods for White Volta at Nawuni and Oti at Saboba were plotted and presented as Figures 2 and 3, respectively. The annual rainfall totals for the two periods which were obtained from the synoptic stations of Tamale, Yendi, Navrongo and Wa have been plotted as Figures 4–7, respectively. The statistics on the time series for each of the two periods for Figures 2–7 were computed and compared. These statistical parameters include the mean, standard deviation (Std. Dev.), coefficient of variation (CV), maximum (Max) and minimum (Min).

4. Results and discussion

Figures 3 and 2 which show significant reductions of runoff for both stations during the second period are summarized in Tables I and II, respectively. The ratio of the mean annual discharge for the second period to the first is 0.769 at Nawuni and 0.675 at Saboba, respectively. Consequently, the percentage reduction of the mean annual runoff observed for the second period is 23.1% and 32.5% respectively for Nawuni and Saboba. There were reductions in the September peak flows of 27.1% at Nawuni and 26.4% at Saboba on the White Volta and Oti, respectively. It is also worthy to note that the October flows have reduced by as much as 44.2% at Nawuni and 54.4% at Saboba (see Figures 2 and 3). These reductions

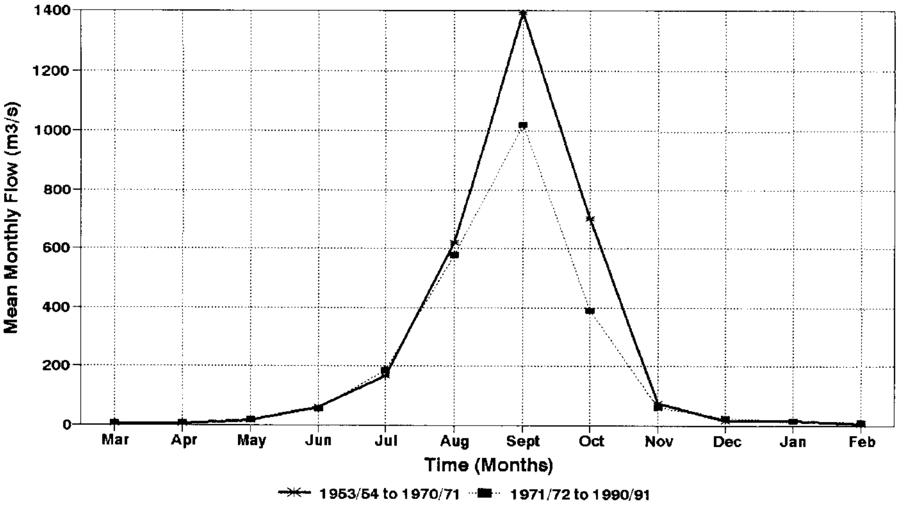

Figure 2. Mean monthly flows at Nawuni station.

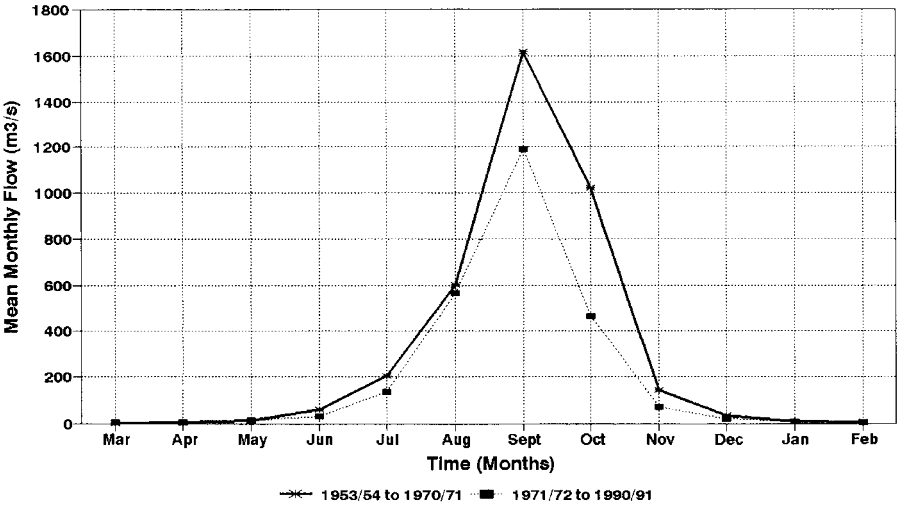

Figure 3. Mean monthly flows at Saboba station.

in the mean monthly flows and the mean annual discharges are significant at the 95% level of confidence.

Since a reduction in rainfall is a primary factor in the reduction of runoff, the rainfall data were analysed for the four synoptic stations, and the rainfall statistics have been presented in Tables III–VI for Tamale, Yendi, Navrongo and Wa. The second period (1971–1990) shows a reduction in the mean annual rainfall of 1.5% for Tamale, 2.3% for Yendi, 7.2% for Navrongo and 11.3% for Wa. These reductions are significant at the 95% level of confidence only for Wa.

TABLE I. Runoff statistics at Saboba

	Annual discharge 1st Period (1953–1970)	2nd Period (1971–1991)
Mean (m^3/sec)	310.03	209.38
Max (m^3/sec)	767.85	347.96
Min (m^3/sec)	35.74	91.47
CV	0.77	0.52
Std. Dev.	187.42	87.03

TABLE II. Runoff statistics at Nawuni

	Annual discharge 1st Period (1955–1970)	2nd Period (1971–1991)
Mean (m^3/sec)	257.17	197.84
Max (m^3/sec)	437.50	443.25
Min (m^3/sec)	141.88	49.77
CV	0.61	0.72
Std. Dev.	81.26	121.78

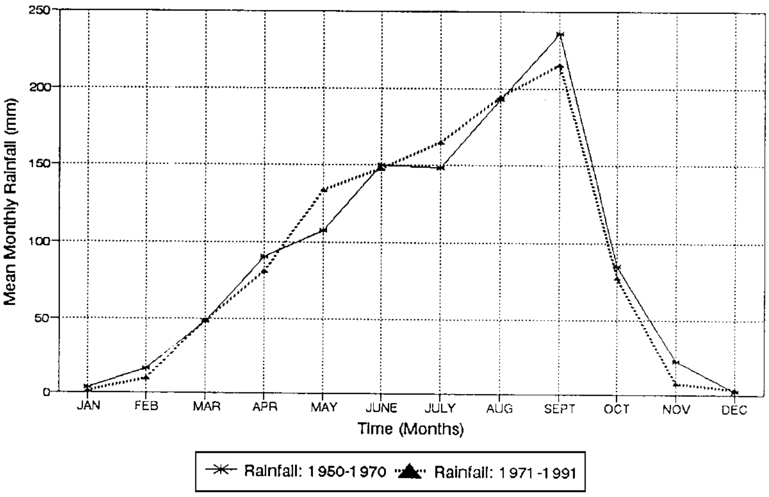

Figure 4. Variation in mean monthly rainfall (mm): Tamale station.

The plot of the mean monthly temperatures for Tamale (Figure 8) shows nearly a 1 °C rise in temperature from 1945 to 1993. Since the capacity of the air for water vapour increases by about 5% or 6% per °C (Rosenberg et al., 1990), there is a corresponding increase in evaporation for this rise in temperature. The annual temperature variations for Tamale are shown in Figure 9.

The changes or reductions in mean annual rainfall over most parts of the basins within Ghana are not significant as analysed from the synoptic stations of Tamale, Yendi and Navrongo; however, the changes or reductions in the discharges during the second period

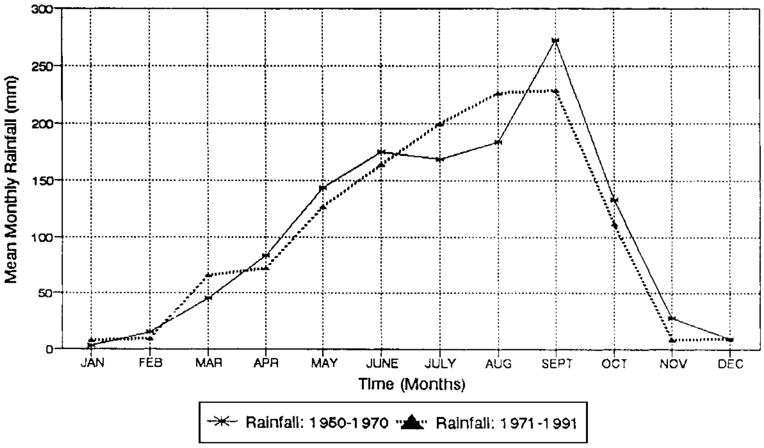

Figure 5. Variation in mean monthly rainfall (mm): Yendi station.

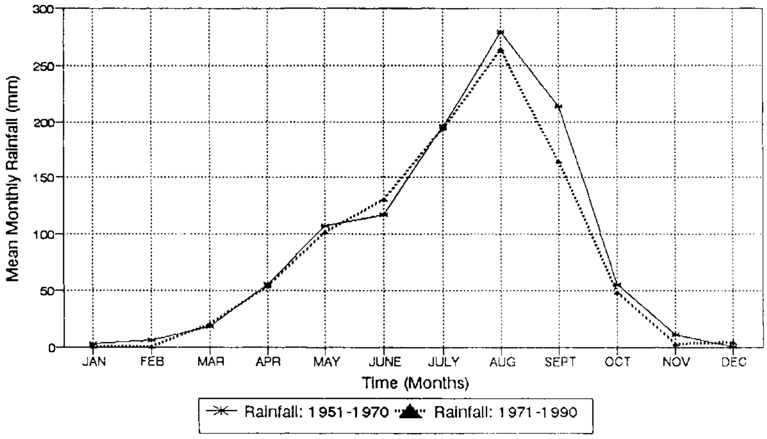

Figure 6. Variation in mean monthly rainfall (mm): Navrongo station.

TABLE III. Rainfall statistics for Tamale

	Annual rainfall 1st Period (1950–1970)	2nd Period (1971–1991)
Mean (mm)	1102.99	1086.11
Max (mm)	1665.22	1579.80
Min (mm)	671.07	748.90
CV	0.23	0.16
Std. Dev.	251.80	174.79

are significant for both basins which affect the Volta lake levels. This may be attributed partly to the rise in temperature in the basins which is giving rise to high evaporation resulting in high water losses in the basins and particularly from the lake surfaces. Secondarily, it is also most probable that the numerous boreholes that have been drilled (over 3000) and are

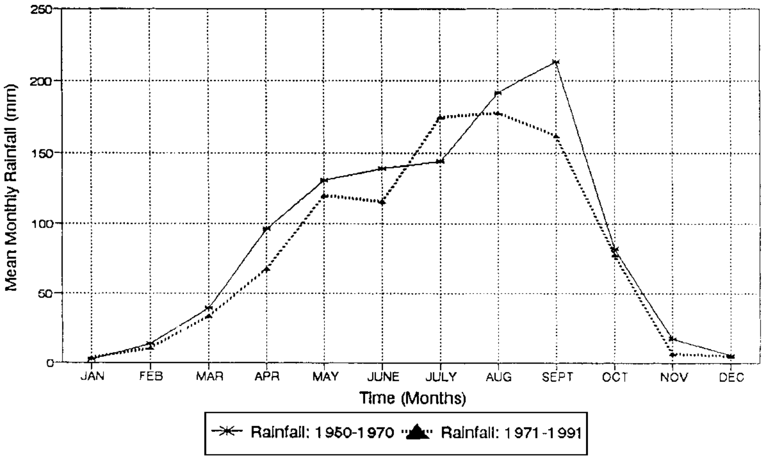

Figure 7. Variation in mean monthly rainfall (mm): Wa station.

TABLE IV. Rainfall statistics for Yendi

	Annual rainfall	
	1st Period (1950–1970)	2nd Period (1971–1991)
Mean (mm)	1257.05	1228.03
Max (mm)	2022.35	1712.00
Min (mm)	777.49	724.70
CV	0.22	0.18
Std. Dev.	271.49	224.83

TABLE V. Rainfall statistics for Navrongo

	Annual rainfall	
	1st Period (1951–1970)	2nd Period (1971–1991)
Mean (mm)	1059.33	982.57
Max (mm)	1276.70	1272.40
Min (mm)	867.40	670.50
CV	0.12	0.17
Std. Dev.	124.95	171.66

being drilled in the basins have the potential of lowering the groundwater table and thereby inducing recharge from the rivers and streams in the basins. Thirdly, the most important reason for the reductions in streamflows is that the rainfall and runoff hydrology have changed significantly outside Ghana towards the north (Sahel) i.e. Burkina Faso and Mali as a result of the natural climatic variability which has been linked to the Sahelian drought. This is so because both the humid and savannah zones of West Africa have been affected by the Sahelian drought of the 1970s and 1980s, although the effect was not evenly spread

TABLE VI. Rainfall statistics for Wa

	Annnual rainfall 1st Period (1950–1970)	2nd Period (1971–1991)
Mean (mm)	1075.46	954.18
Max (mm)	1542.80	1329.94
Min (mm)	762.76	521.40
CV	0.20	0.19
Std. Dev.	213.57	177.70

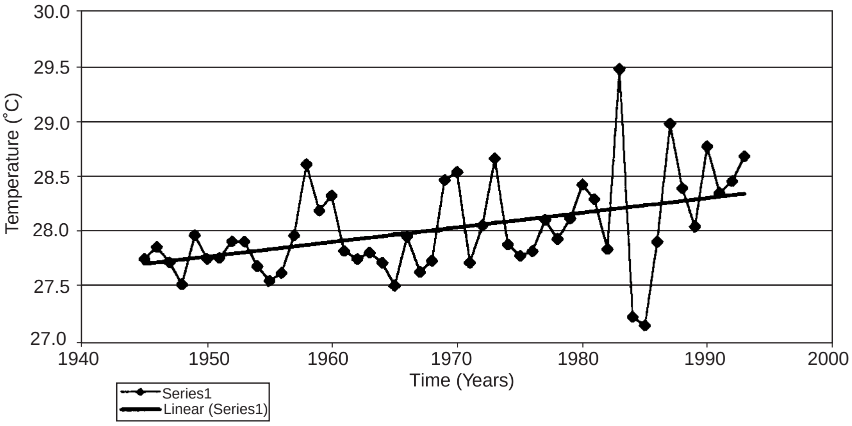

Figure 8. Variation in mean temperature: Tamale.

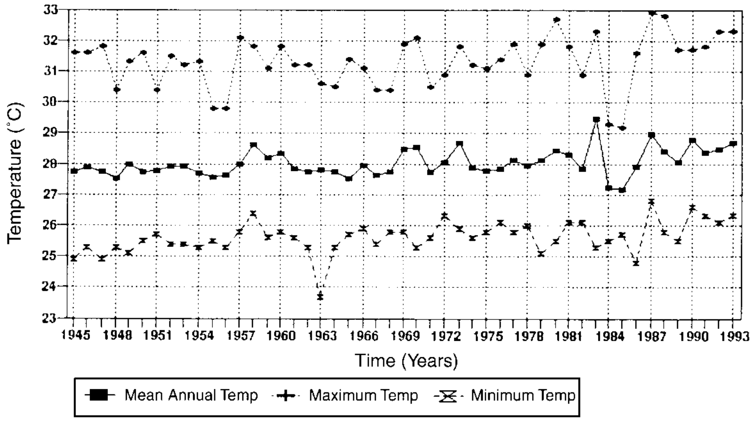

Figure 9. Variation in temperature: Tamale.

(Servat et al., 1997; Paturel et al., 1997). Ghana was one of the least affected (Paturel et al., 1997). This has been confirmed by the earlier analyses of rainfall in the study areas which showed that only one out of the four synoptic stations recorded a significant reduction in rainfall after 1970.

5. Conclusion

This study in the White Volta and Oti river basins, which are among the major contributors to the Volta lake, shows that rainfall from the first period (1950–1970) has reduced by 1.5%, 2.3%, 7.2% and 11.3% respectively during the second period (1971–1990) at Tamale, Yendi, Navrongo and Wa. Although the change or reductions in rainfall over most of the study basins within Ghana is not significant, the analyses show significant reductions in the mean annual flows of 23.1% and 32.5% at Nawuni on the White Volta and Saboba on Oti while the September peak flows have reduced by 27.1% and 26.4%, respectively. This may be due to the induced recharge from the river systems resulting from abstractions from the numerous boreholes which have the effect of lowering the groundwater tables. A second reason is most probably due to increase in evaporation in the river basins as a result of the observed 1°C rise in temperature. Lastly, the most prominent reason is that the rainfall and runoff hydrology have changed considerably outside Ghana towards the Sahel where the sources of the rivers are located as a result of the natural climatic variability which has been linked to the Sahelian drought. It is the combination of all or some of these factors which have contributed to the observed reductions of streamflows into the Volta lake and the result is the periodic decline in the lake levels.

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